A longitudinal study of infant sleep and its effects on cognitive development

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Doctoral Thesis

A longitudinal study of infant sleep and its effects on cognitive development

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Declaration of Authorship

I, Manuela Pisch, declare that this thesis titled, 'A longitudinal study of infant sleep and its effects on cognitive development' and the work presented in it are my own.

Signed: ____________________________________

Date: ____________________________________

BIRKBECK, UNIVERSITY OF LONDON

Abstract

Centre for Brain and Cognitive Development
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Doctor of Philosophy

A longitudinal study of infant sleep and its effects on cognitive development

by Manuela Pisch

Sleep is a common behaviour in all animals and crucial for physiological, social, emotional, and cognitive functioning. Previous studies have demonstrated the importance of sleep for cognition in adults, in particular with respect to attention and memory (Maquet, 2001; Diekelmann & Born, 2010). However, the role of sleep in developing infants has hitherto been relatively neglected. For instance, we do not know exactly whether and how sleep impacts on cognitive functioning nor which aspects of sleep matter more than others during this decisive period of life.

We designed a cross-sectional and longitudinal study in order to explore these questions. Forty infants were followed longitudinally, measuring their sleep patterns with actigraphy for a week at months 4, 6, 8, and 10. Additionally, parents filled in a sleep diary and monthly questionnaires on sleep, cognitive, social, and motor development, as well as infant and parent sleep problems. Furthermore, three cognitive tasks using eye-tracking were conducted at each age.

Sleep patterns changed most between 4 and 6 months: older infants had longer and less fragmented sleep duration. Regarding the eye-tracking tasks, we found a non-linear response over developmental time on the short-term memory task as well as an amelioration in number processing and shorter disengagement latencies. Habitual sleep was found to relate to short-term memory performance and number processing but not to reaction time or disengagement of attention. The association of sleep to cognition was stronger with respect to sleep fragmentation than to sleep duration. In general, infants with less time awake during the night performed better on the eye-tracking tasks. The discussion proposes explanations for what drives the differential associations of cognition with sleep duration/fragmentation and examines how the limitations of this work can inform future studies.

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Firstly I would like to thank all the families who participated in this research, without whom this thesis would not have been possible. In particular, I felt very grateful and attached to those families who participated in the longitudinal study, where I could see the infants grow and develop so quickly.

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Abbreviations

EEG	**E**lectro**e**ncephalo**g**raphy
EOG	**E**lectro**o**culo**g**raphy
EMG	**E**lectro**m**yo**g**raphy
ERP	**E**vent-**r**elated **p**otential
REM	**R**apid **e**ye-**m**ovement sleep
N-REM	**N**on **r**apid **e**ye-**m**ovement sleep
ADHD	**A**ttention-**d**eficit/**h**yperactivity **d**isorder
BSID	**B**ayley **S**cales of **I**nfant **D**evelopment
MDI	**B**ayley **M**ental **D**evelopment **I**nventory
BISQ	**B**rief **I**nfant **S**leep **Q**uestionnaire
PCI	**P**arent-**c**hild-**i**nteraction
SES	**S**ocio-**e**conomic **s**tatus
RT	**R**eaction **t**ime
OFS	**O**bject-**F**ile **S**ystem
ANS	**A**nalogue **N**umber **S**ystem

Contents

List of Figures

List of Tables

Chapter 1

Context and Purpose of the Research

Sleep is a universal behaviour of all mammals, birds, and reptiles (Stickgold & Walker, 2009). In adults, it not only serves important functions such as the maintenance of the immune performance (Everson & Wehr, 1993), arousal regulation (Dahl, 2009), and the preservation of brain plasticity (Frank, Issa, & Stryker, 2001) to name just a few, sleep also greatly impacts cognitive performance, e.g., learning and memory consolidation (Diekelmann, Wilhelm, & Born, 2009; Walker, 2009; Diekelmann & Born, 2010). Surprisingly, sleep is a neglected topic in developmental research, and whether it plays the same role during the first years of life has not been explored so far. There are two reasons to assume that sleep during development is differently weighted in importance than later in life. First, infants' sleep variables differ substantially from those in adulthood. For example, infants have a much higher need in sleep compared to adults and spend more time asleep than awake (Davis, Parker, & Montgomery, 2004). Moreover, waking up to feed is necessary throughout the first months of life but not any more in adulthood. Second, the individual variability with respect to important sleep variables of sleep duration and sleep fragmentation is considerable during development (e.g., Galland, Taylor, Elder, & Herbison, 2012). Because the first year of life is also particularly crucial for the subsequent socio-cognitive development of the child, we can ask the important question of whether these inter-individual sleep differences relate to other aspects of development such as performance in attention and memory. Only by identifying sleep variables that are associated with developmental delays, is it possible to design effective interventions.

However, studies that relate sleep variables during development with cognitive performance are rare and almost no longitudinal studies on typically developing infants exist. This is particularly remarkable when considering how crucial a topic it is for parents. Working in a babylab, I quickly realised that their infants' sleep is amongst the most frequently discussed topic by parents. This immense gap in numbers of studies between infant and adult research can mostly be attributed to methodological issues. On the one hand, it is much more difficult to assess infants' habitual sleep compared to the sleep patterns of adults. For instance, when testing infants the use of sleep laboratories is only feasible with small sample sizes. Furthermore, studies involving sleep deprivation are ethically not allowed for developing populations and external factors are very difficult to control. On the other hand, it is more difficult to measure infants' cognitive performance compared to that of adults. Since infants are non-verbal, special techniques such as eye-tracking are often used in order to draw conclusions about the child's developmental status. Both points taken together make it more difficult to compare sleep variables with cognitive measurements in developmental studies and to generalise the findings.

Nevertheless, aiming to better understand the role of habitual sleep for cognitive performance during development is crucial. It helps to comprehend in more detail the function of sleep and is critical for studying other aspects of development. It is essential to answer questions like: can sleep difficulties / abnormal sleep variables serve as an early marker for altered developmental trajectories in socio-cognitive functioning? What sleep variables are more related to cognitive outcomes than others? And are those associated to particular parenting techniques at bedtime? Finally, it could help many infants with sleep difficulties and insecure parents who do not know how to deal with them.

Together with my supervisors, I therefore designed a study which is unique in the infant sleep and cognition literature because it is both cross-sectional and longitudinal. Our purpose was to examine in the same infants the importance of sleep for cognitive development over the first year of life in the same infants. We thereby wanted to investigate the relevance of different sleep variables, such as sleep duration and sleep fragmentation, for different cognitive outcomes, such as memory and attention. By doing so, we also aimed to better define high quality sleep during development.

More precisely, 40 infants were followed longitudinally, measuring their sleep variables with actigraphy for a week at months 4, 6, 8, and 10. Additionally, parents filled in a sleep diary and bi-monthly questionnaires on sleep, on cognitive, social, and motor development, as well as on infant and parent sleep problems. Furthermore, three cognitive tasks using eye-tracking were conducted at each age assessing general processes such as attention and memory development as well as a specific cognitive domain, numerical sensitivity.

The specific research questions of this project were:

1. What are the developmental changes in habitual sleep within our sample with respect to different sleep variables (e.g., fragmentation, efficiency, and duration)?
2. How does the performance in the three eye-tracking tasks on attention, short-term memory, and number processing change between 4 and 10 months – is it linear, random, U-shaped...?
3. Are there any associations between the sleep variables and performance on the cognitive tasks? And if so...
   (a) Are some sleep variables more related to cognition than others? In other words, can we define infant high quality sleep more precisely? For instance, we do not know whether a long but fragmented or a short but undisturbed sleep is better.
   (b) Are there only concurrent or also longitudinal associations between sleep and cognition?
   (c) Is there a time during the first year of life when the relation between sleep and cognition is stronger?

This thesis will first review the background of human sleep research and the role of sleep for cognition in an introductory chapter (Chapter 2). Then, I will describe the different methods that were used in this longitudinal study (Chapter 3) as well as the design and procedure of the study (Chapter 4). Results will be reported in Chapters 5 to **??**. First, I will focus on the definition, coding, and the descriptive analyses of the sleep variables (Chapter 5) in order to outline characteristic infant sleep and its development over time. Furthermore, I will report the relation of sleep variables with aspects of the social context, i.e., the bedtime environment and the socio-economic background (Chapter 6), as well as with the scoring in a questionnaire on general development (Chapter 7). The following three chapters will concentrate on the relation between sleep and cognition in development and will each focus on the results of one cognitive eye-tracking task: the short-term memory task in Chapter 8, the visual attention task in Chapter 9, and the numerical sensitivity task in Chapter 10. The thesis will conclude with a general discussion (Chapter 11).

Chapter 2

Introduction

2.1 Sleep: an overview

Curcio, Ferrara, and De Gennaro (2006) defined sleep as "an active, repetitive, and reversible behaviour serving several different functions, such as repair and growth, learning or memory consolidation, and restorative processes: all these occur throughout the brain and the body. Thus, during sleep behavioural, physiological, and neurocognitive processes occur: these very processes are susceptible to be impaired by the absence of sleep.". Other characteristics of sleep were summarised by Peigneux, Laureys, Delbeuck, and Maquet (2001) as well as Stickgold and Walker (2009): a recognisable posture, reduced responsiveness to external stimuli, and regulated duration and intensity through homeostatic processes and a circadian rhythm. Moreover, they stated that sleep deprivation in adults usually leads to a rebound and that the sleeping person experiences less consciousness, shows attenuated motor output, as well as has characteristic EEG-patterns.

In this chapter, I will first give a short overview of the most important terms in the sleep literature and summarise hypotheses on the function of sleep. Secondly, I will describe norms of adult and infant human sleep.

2.1.1 Biological rhythms

All living beings go through a 24-hour cycle, which is called a circadian rhythm. Many biological processes in humans such as temperature, hormone release, and muscle performance actually fluctuate in this rhythm. The first study investigating this mechanism was done by Jean de Marian in 1729 who investigated changes in plants (de Marian, 2014, p.35). He observed that a certain species of heliotrope plant opened and closed the leaves regularly in a 24-hour-rhythm. In order to test whether this could be explained by changes to sunlight exposure, he placed the plants in a dark room and was surprised that the leaves continued to open and close with the same rhythm. However, de Marian did not interpret this behaviour as a marker for an endogenous rhythm but explained it by temperature cycles, light leaks, or changes in other meteorological parameters. Today we know that biological rhythms are shaped by both internal mechanisms as well as external stimuli.

2.1.1.1 Endogenous periodicity

Studies of free running biological rhythms have shown that most living beings have an internal body clock that influences those processes even if the body is cut off from the outside world (Aschoff, 1965; Saunders, 2002; Dunlap & Loros, 2006; McClung, 2006). This clock is also called endogenous periodicity or pacemaker. One of the most important endogenous mechanisms that regulate our internal clock is the Suprachiasmatic Nucleus in the hypothalamus (Bernard, Gonze, Čajavec, & Herzel, 2007). The hypothalamus is a brain region related to many aspects of body regulation such as hormones, temperature, and eating behaviour (Swaab & Aminoff, 2004). About 20.000 cells make the Suprachiasmatic Nucleus and fire in a circadian rhythm (Aton & Herzog, 2005). Damage to this nucleus has dramatic effects on biological rhythms in the body, e.g., circadian periodicity in activity, hormone secretion, drinking behaviour and sleep (Stephan & Zucker, 1972; R. Y. Moore & Eichler, 1972). The firing rate of the Suprachiasmatic Nucleus seems to be unrelated to any input from the rest of the brain (Inouye & Kawamura, 1979) leading to the assumption that humans have indeed an internal and independent clock.

Another important mechanism that regulates body rhythms is the release of different hormones at certain times of the day that influence sleep / wake patterns. For example, melantonin is the hormone known as the "sleep hormone" because there is a much higher concentration in the blood in the evening and at night (Altun & Altun, 2007). Hormones and sleep / wake rhythms interact with each other (Brown, 1994). For some hormones, such as the growth hormone, their release is provoked by sleep and and some hormones, such as melantonin, trigger themselves sleep onset (Takahashi, Kipnis, & Daughaday, 1968).

2.1.1.2 Exogenous periodicity

Since the internal body clock is not perfectly accurate, living beings need external stimuli, called zeitgebers or exogenous periodicity, in order to synchronise biological rhythms with the outside world. The most important zeitgeber is the change of light between day and night. For example, the release of melantonin is regulated via the dark-light-cycle (Brown, 1994). If there were no external stimuli, some people would rather live in a 23-hour-rhythm whereas most people would experience a somewhat longer one than 24 hours. In other words, the endogenous periodicity is variable between individuals (Phillips, 2009). For instance, Czeisler et al. (1999) found that without external stimuli, their participants had a mean cycle length of 24.18 hours with some inter-individual variability.

In summary, circadian rhythms influence how we get tired in the evening, when we fall asleep, and when we wake up in the morning. From a developmental perspective circadian rhythms are a particularly interesting and crucial topic to study because they still have to emerge fully over developmental time. For infants, it is a challenge to actually learn to regulate themselves and adapt to a circadian rhythm (Mirmiran, Maas, & Ariagno, 2003). Before birth, foetuses are still "attached" to their mother's clock; but after birth, their own endogenous rhythm has to start off (Mirmiran, 1991). A stable circadian sleep / wake pattern only emerges after some months and is dependant on the care environment (Thomas, 1995). In this context, it also makes a difference whether infants are breast-fed and consequently affected by the hormones in the mother's milk (Illerova, Buresova, & Presl, 2013) or whether they are formula fed that does not change its consistency with the time of the day. In section 2.1.4, I will therefore discuss in more detail how sleep patterns and circadian rhythms emerge over developmental time.

2.1.2 Hypotheses on the function of sleep

Examining the effects of sleep deprivation is probably the most popular method hitherto used to investigate the importance of sleep. Studies with rats for instance, have shown that rats die within 3 weeks if they are kept constantly awake (Everson, Bergmann, & Rechtschaffen, 1989). Sleep deprivation in human adults has a negative impact on many physiological, neuro-cognitive, and behavioural processes such as on body temperature, mood, decision making, and brain plasticity (Horne, 1978; Pilcher & Huffcutt, 1996; Frank et al., 2001; Harrison & Horne, 2000). However, although we are aware of the numerous detrimental effects of sleep deprivation, it is hard to merge those findings, to capture the bigger picture, and to really answer the question of why we sleep. Consequently it is difficult to clearly define the function of sleep, so I will therefore summarise the most important hypotheses.

There are two evolutionary approaches that aim to explain why sleep emerged as a behaviour. Firstly, it has been suggested that sleep emerged during evolution in order to **preserve and protect** animals (Meddis, 1975) – staying quiet and hidden prevents them from being exposed to predators. Another evolutionary approach is the **Hybernation Theory** from Webb (1974) who claims that sleep is an adaptive behaviour that helps animals to save energy (see also Berger & Philips, 1995). Reasons for this assumption are, for instance, that smaller animals with higher heat loss sleep for larger periods than larger ones, carnivores with a more efficient food intake sleep more than herbivores, species with a greater total sleep time have generally higher core temperatures and a higher metabolic rate, and in general animals use to sleep more when food is scarce. The problem with these types of evolutionary approaches is that they are not falsifiable although examples of animals can be found, which do not support the hypotheses. Moreover, they do not explain the harmful effects of sleep deprivation. Finally, all animals sleep, even those without predators. However, if the only reason why animals sleep were because of energy conservation, there ought be species which would not need to sleep.

Another proposed function of sleep is the discharge of emotions, called the **Overnight Therapy Hypothesis** (van der Helm & Walker, 2009). It has been suggested that affective experiences are reprocessed during sleep – which may also result in dreams – and that the whole neural system involved in emotion regulation is reset. This hypothesis is supported by research showing that sleep is important for stress relief and that abnormal sleep variables are related to increased internalising and externalising behavioural problems (van der Helm & Walker, 2009).

Ian Oswald and Jim Horne both proposed that sleep has a **restorative function** (Oswald, 1966; Horne, 1988). This hypothesis has been underpinned by numerous studies demonstrating the beneficial effects of sleep on the body, brain, and general health. For instance, important interactions between sleep and the endocrine and immune system have been identified (Akerstedt & Nilsson, 2003). With respect to brain restoration, sleep has been associated with cerebral protein synthesis (Benington & Frank, 2003) and may generally upregulate several genes that are important for structural components of neurones (Cirelli, Gutierrez, & Tononi, 2004). Finally, recent research suggests that sleep is essential for "cleaning" the brain (Xie et al., 2013). The spaces between neurones in the brain contain a fluid that is filled with molecules secreted from brain cells, which normally assemble into a matrix that helps to hold other neurons in place. However, it also contains neurotoxins and misfolded proteins that play a role in neurodegenerative brain diseases, i.e., dementia and Parkinson. During sleep, neurons shrink so that the extracellular space expands and the fluid flow is triggered, resulting in the removal of the harmful molecules.

2.1.2.1 The role of sleep for cognition

Probably the most important aspects of cognition that are influenced by sleep are memory and learning (Walker, 2009; Stickgold & Walker, 2009; Diekelmann & Born, 2010, for review), abstraction (Fenn, Nusbaum, & Margoliash, 2003), and attention (Lim & Dinges, 2008).

With respect to sleep-dependent memory consolidation, two hypotheses have been suggested and studied (Walker, 2009, for review). The first is the **Hippocampal-Neocortical Dialogue Model** (Frankland & Bontempi, 2005; Molle & Born, 2011) proposing that the hippocampus initially integrates information that has been encoded in different cortical areas. Reactivation of the hippocampal-cortical network during sleep results in a strengthening of specific activations in the cortex. This subsequently creates a coherent image, which permits integration of the new memory while becoming gradually independent of the hippocampus. There is even some initial evidence that sleep supports memory consolidation in non-mammalian animals in a similar way (Vorster & Born, 2014, for review). The second hypothesis, the **Synaptic Homeostasis Hypothesis**, suggests that sleep is needed to hold at a reasonable level the number of connections between neurones in the brain (Tononi & Cirelli, 2014). Through daytime experiences, connections are built between neurones. If those or other connections are not regularly cut, increasing energy would be needed. It is therefore during sleep that unimportant connections are removed, which may also explain how we create rules and abstract from what we have learned. Bushey, Tononi, and Cirelli (2011) recently demonstrated this to be the case in fruitflies. Moreover, Huber, Felice Ghilardi, Massimini, and Tononi (2004) conducted a study with humans where the learning of a task during the day triggered locally specific increases in slow-wave activity during night sleep, which probably promotes the decrease of synaptic connections.

Regarding attention, sleep plays a role in **maintaining the functional integrity of fronto-parietal networks**. Well-rested humans are usually only able to maintain their attention at a maximum level for a short amount of time, but sleep deprivation results in even more unstable attention abilities (Doran, Van Dongen, & Dinges, 2001). Sleep-deprived drivers, for instance, are less able to control their attention, hence increasing the risk of accidents (Marcus & Loughlin, 1996).

Importantly, the described hypotheses on the function of sleep rely on adult human and animal studies, but fail to explore the importance of sleep during development. It is possible that subtle differences in sleep variables early in life could affect cognitive, behavioural, and physiological functioning even more than in adults, which may cascade over developmental time and lead to considerable long-term consequences. But it is also possible that infants are more resilient than adults with respect to sleep problems. Since sleep has been shown to be particularly important for attention and memory, and since both aspects are crucial for optimal infant development (e.g., Nelson & Webb, 2002; Scerif, 2010), I decided mainly to focus on memory and attention and their links to sleep in my PhD project.

2.1.3 Adult sleep

Nowadays, adults sleep on average about 7.5 hours per night. Nowadays, adults sleep on average about 7.5 hours per night. The National Sleep Foundation recommended in a recent report where experts from sleep, anatomy and physiology, as well as paediatrics, neurology, gerontology and gynaecology came to a consensus about optimal sleep durations that young adults (18-65 years old) should sleep 7 to 9 hours per night whereas for older adults (+ 65 years old) 7 to 8 hours is sufficient (Hirshkowitz et al., 2015). There is no magic number of hours that one should sleep because sleep needs depend on many factors such as genes, life style, and age. In general, human adults in the western world probably sleep less than they should, and sleep duration has been decreasing over the last decades. One study recorded sleep durations from sleep diaries in full-time workers between 1975 and 2006 (Knutson, Van Cauter, Rathouz, & DeLeire, 2010). The number of people sleeping less than 6 hours per night increased significantly over time. This fact has also been replicated in a study from the National Health Interview Survey in the US: the percent of working adults reporting a sleep duration of 6 hours or less per night had increased from 24% to 30% between 1980 and 2010 (Luckhaupt, Tak, & Calvert, 2010). If, and how much, these partial sleep restrictions and deprivations that were likely caused by changing working habits may affect quality of life and cognitive performance has still to be examined.

2.1.3.1 REM, N-REM, and wakefulness

In 1955, Aserinsky and Kleitman initially discovered the distinction between rapid eye movement sleep (REM) and non-rapid eye movement sleep (N-REM) (Aserinsky & Kleitman, 1955). Two years later Dement and Kleitman demonstrated differences in electrical activity between REM and N-REM (Dement & Kleitman, 1957). Those differences between wakefulness, REM, and N-REM can be found when recording activity at the scalp (Electroencephalography: EEG), at the eyes (Electrooculography: EOG), and on muscles (Electromyography: EMG) (e.g., Stickgold & Walker, 2009). The EEG during REM sleep shows very fast and desynchronised brain activity that is more random than during N-REM sleep. It resembles activity recorded during wakefulness. EOG measures of an awake person and a person in REM sleep are also similar to each other and different from N-REM sleep. During wakefulness and REM sleep the eyes are moving together, up and down, right and left, and stop sometimes; during N-REM there is very little activity. However, REM sleep is very different from N-REM sleep and wakefulness with respect to the activity patterns measured with EMG. The body is practically paralysed during REM sleep but moves in N-REM sleep. In the past, dreams have been associated with REM sleep only. However, more recent findings suggest that we also dream during N-REM sleep even though those dreams seem to be less vivid (Carskadon & Dement, 2011). Still there are hypotheses about the different functions of REM and N-REM sleep. For instance Diekelmann and Born (2010) argue for different roles of REM and N-REM sleep as far as memory consolidation is concerned.

Sleep stages Adult sleep is characterised by the periodic transition of 5 sleep stages and is often presented in a hypnogram – a figure that shows sleep cycles and transitions from one stage to the next over the length of a night (see as example Figure 2.1 taken from Gander, 2003). Usually, adults enter sleep through N-REM sleep and experience therein the first 4 stages, which differ in the depth of the sleep (see Carskadon & Dement, 2011, for review). Stage 1 is characterised by a relaxed wakefulness with a synchronised EEG-pattern consisting of alpha waves (about 2% of the night). People fall into light sleep in stage 2 (about 45% of the night). The typical EEG shows theta waves and first sleep spindles, which are bursts of oscillatory brain activity. In stage 3 a person is finally fully asleep, with this stage being marked by the appearance of delta waves (about 3% of the night). Stage 4 is the deepest stage of sleep, with the EEG being dominated by delta waves (about 10% of the night). This deep sleep normally only occurs during the first hours of the night and is called slow-wave sleep. Towards the end of the night, sleep is generally less deep but has a higher proportion of REM sleep (about 20 - 25% of the night). Normally, people first pass through the 4 N-REM sleep stages and then spend a period of time in REM sleep before passing again into stage 2. One normal sleep cycle lasts on average 90 minutes. N-REM or slow-wave sleep predominates the first third of the night whereas people have more REM sleep in the last third of the night.

2.1.4 Sleep during development

Sleep cycles in the **foetus** with alternating periods of rest and activity, can already be observed from the second trimester onwards (Graven & Browne, 2008) by examining real-time ultrasonography (Fukushima, Morokuma, & Nakano, 2006). Between about week 20 and birth, these sleep states continue to develop systematically (Kleitman, 1982), becoming fully normal sleep cycles at about week 35 (Gómez, Newman-Smith, & Breslin, 2011, for review). **Newborns** sleep approximately 16 to 18 hours per day, even though

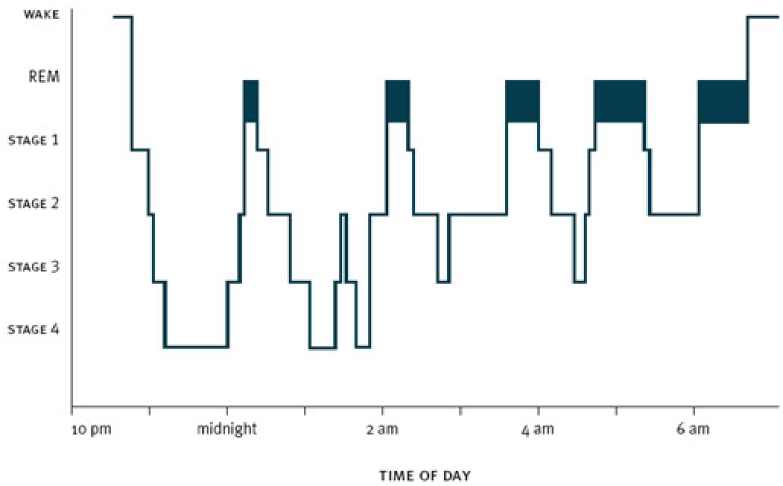


FIGURE 2.1: Example of a hypnogram taken from Gander (2003).

the longest continuous sleep period is only about 2.5 to 4 hours long (Adair & Bauchner, 1993). The characteristic sleep / wake pattern of a newborn and very young infant is highly irregular and influenced by the need to feed (Butte, Jensen, Moon, Glaze, & Frost, 1992). Since mothers' milk is digested relatively quickly, newborns and infants have to be fed often – one reason for the great number of awakenings and the short periods of continuous sleep duration. A circadian sleep / wake cycle only starts to arise at about 2 to 3 months after birth (Sheldon, 2005). This is the result of the emerging cyclicity of several physiological processes such as a 24-hour core body temperature cycle at 1 month of age, prolonged nocturnal sleep periods at 2 months, and a circadian rhythm in melantonin and cortisol hormone release at 3 months (Jenni & Carskadon, 2000). Also, the newborn sleep architecture remains very different from adult sleep with only 3 distinguishable phases: quiet sleep, active sleep, and intermediate sleep (Davis et al., 2004). In contrast to adults, newborns enter sleep directly through REM sleep, not N-REM, and one sleep episode consists of only one or two sleep cycles (Davis et al., 2004). In 3-month-old **infants**, sleep architecture becomes more adult-like, with sleep onset occurring through N-REM and then passing to REM sleep (Jenni & Carskadon, 2000). Moreover, the longest continuous sleep duration increases to about 6 hours by 6 months of age (Anders, Sadeh, & Appareddy, 1995) and thereafter does not change significantly before the first birthday (J. Henderson, France, & Blampied, 2011). In general, infants gradually adapt to a sleep / wake pattern with longer sleep periods, but sleep variables remaining rather unstable throughout the first three years of life (Scher, Epstein, &

Tirosh, 2008). During childhood, habitual sleep becomes more consistent (Gómez et al., 2011). While young children still need several naps throughout the day, older children increasingly adapt to an adult-like rhythm consisting of nocturnal sleep only (Jenni & Carskadon, 2000). Adolescence is often characterised by sleep deprivation and alterations in sleep / wake rhythms, which originate from socio-environmental factors, e.g., access to television, video games, and computers as well as the increasing importance of peers (Carskadon, 2002).

A report published in the Journal of Sleep Health, the National Sleep Foundation recommended optimal sleep durations for different age groups which were defined by an expert panel of researchers from different disciplines (Hirshkowitz et al., 2015). For newborns (0 - 3 months), they suggested a total sleep duration of 14 to 17 hours each day, for infants (4 to 11 months) this is 12 to 15 hours, and for toddlers (1 to 2 years) their recommendation was a sleep duration of 11 to 14 hours per day. Three- to 5-years-old preschoolers should sleep 10 - 13 hours, 6- to 13-years old school children need 9 to 11 hours of sleep, and teenagers (14 to 17 years) would optimally sleep for 8 to 10 hours.

2.1.4.1 Measurements of sleep

Polysomnography The gold standard for measuring sleep is polysomnography – a combination of EEG, EMG, EOG, and sometimes additional physiological measures such as pulse rate. The detailed information gained by polysomnography makes it possible to identify sleep stages and consequently to distinguish precisely sleep from wake periods. Thereby it is considered to be the most reliable tool that we have. However, polysomnography can also disturb and consequently alter the sleep of an individual, and data can only be collected while the person is attached to the devices. Hence, recording is normally minimised to about 8 hours.

Actigraphy Actigraphy is the use of a movement detector in order to estimate periods of activity and inactivity, which help to identify sleep and wake episodes. It is frequently applied in infant research due to its ease of use and because it gives more information compared to subjective parent-report measures (see, for example, Sadeh, 2011; Ashworth, Hill, Karmiloff-Smith, & Dimitriou, 2013). Since actigraphy was employed in this project to detect sleep / wake patterns, I will summarise sleep norms gained by this method in greater detail. I will dwell on actigraphy as a method more comprehensively in section 3, e.g., by describing how it works.

Research on infants that uses actigraphy to assess sleep variables mainly focussed on two different types of variable: those that relate to sleep duration and those that relate to sleep fragmentation. In my thesis, I followed the recommendations of Meltzer, Montgomery-Downs, Insana, and Walsh (2012) who describe those variables and suggest ways to calculate and report them.

There are several variables that relate to **sleep duration** and that differ slightly: for instance, average time spent in bed includes the times awake, whereas total sleep time only takes into account the actual time asleep. A meta-analysis by Galland et al. (2012) summarises sleep durations in infancy, toddlerhood, and childhood (up until 12 years) reported across 34 studies. These sleep durations are presented in Figure 2.2. Two aspects are apparent when examining the graph. First, infants sleep increasingly less over developmental time, with the most important change occurring within the first 6 months. Second, there is a high inter- and intra-individual variability particularly in the first months, which decreases over developmental time. The obvious question to ask here is whether this variance accounts for differences in other aspects to development and I will come back to this issue in section 2.2 on sleep and cognition.

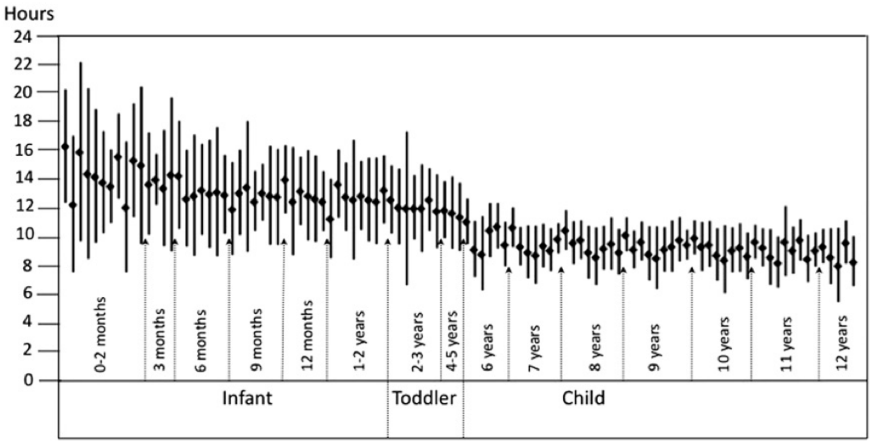


FIGURE 2.2: Sleep duration across ages as reported in 34 reviewed studies (Galland et al., 2012). Data are presented as the mean ±1.96 SD.

Sleep fragmentation is often described as the total time the infant is awake during the night after sleep onset in the evening or as the number of awakenings. The number of night wakings drops significantly in the first 6 months and then stays relatively stable (Galland et al., 2012). According to a meta-analysis by Meltzer et al. (2012), the most prominent variable of sleep fragmentation reported in the infant sleep literature is sleep efficiency, which is the proportion of time asleep during one night as a function of total sleep duration.

Video recordings It is possible to video-record participants while they are sleeping in order to identify sleep and wake episodes. Normally, those video recordings are divided into 30-second epochs and each epoch is coded as awake or asleep (Sivan, Kornecki, & Schonfeld, 1996). An advantage of video recordings compared to polysomnography is that they can be done in the home environment of the person. Moreover, validation studies with polysomnography showed that sensitivity of cideo recordings is very high – this method accurately determined 95% of the sleep epoch (Morielli, Ladan, Ducharme, & Brouillette, 1996). However, specificity, which is the accuracy in detecting wake epochs, was just 80% compared to polysomnography. The disadvantage of video recording is that coding is very time consuming and therefore it is usually not done for a number of nights in a row. Also, it is not possible to video record nap times in infant studies when infants are not in a bedroom but for instance in a pushchair or carried around.

Parent- / Self-report Many studies use subjective measures of sleep because of feasibility issues. There are a number of questionnaires available in order to collect data on sleep duration and sleep fragmentation (e.g., Brief Infant Sleep Questionnaire, Sadeh (2004)), sleep habits (e.g., Sleep Habit Questionnaire, Owens, Spirito, and McGuinn (2000)), and sleep problems (e.g., is also assessed by Sadeh's Brief Infant Sleep Questionnaire, Sadeh (2004)). Compared to questionnaires, which give a very board idea of sleep-wake patterns, there are also sleep diaries, in which participants note their sleep and nap times as well as awakenings for a certain period of time. Although, sleep questionnaire and diaries are much less time consuming, invasive, and easier to carry out than objective measures of sleep, they often do not assess sleep variables reliably and accurately. For instance, in infant studies, parental report did not correlate with actigraphy for measures of sleep fragmentation (Werner, Molinari, Guyer, & Jenni, 2008).

2.1.4.2 Sleep problems in typical development

Insomnia Insomnia Over the lifespan, insomnia is by far the most common sleep disturbance (Ohayon, 2002). It is defined as the difficulty of initiating and maintaining restorative sleep and characterised by awakenings that occur more often than desired or by a reduced sleep quality (Ohayon & Roth, 2001; Thorpy, 2012). In a poll from 1979, 95% of a randomly selected sample of adult participants reported that they experienced symptoms of insomnia at some time in their life (The Gallup Organization, 1979). However, most of those adults only experienced the symptoms for a short amount of time. In a review analysis of Ohayon (2002), prevalence estimates for chronic insomnia ranged from 4.4% to even 48% – a wide range that is also caused by different definitions of insomnia used in the studies. With strict diagnostic criteria of the DSM-IV only up to 11.7% of the population experience chronic symptoms of insomnia.

In infancy and childhood behavioural insomnia is very common and can affect up to 25% of the children (J. Lipton, Becker, & Kothare, 2008; Vriend & Corkum, 2011). For infants during the first year of life, the main sleep problem is the difficulty to self-sooth (Vriend & Corkum, 2011). Arousal at the end of each sleep cycle is normal but it is crucial that the infant learns how to self-sooth and fall back to sleep without the help of the parent. The prevalence of infants with symptoms of behavioural insomnia is about 20% to 30% (Meltzer, Johnson, Crosette, Ramos, & Mindell, 2010). Later in development, children more commonly start to refuse to go to bed, delay bedtime, or experience nightmares (Vriend & Corkum, 2011). Liu, Liu, Owens, and Kaplan (2005) suggested this is caused by inappropriate limit setting of the caregivers and affects 30% of the children between 2 and 6 years.

Sleep disordered breathing Symptoms of sleep breathing disorders are snoring and recurrent episodes of apnea during sleep (Thorpy, 2012). Often this is accompagnied by daytime sleepiness, insomnia, or the difficulty of breathing during sleep. In adults, the prevalence varies widely between different populations; for instance snoring occurs in 2% to 86% of the adults (Kryger, Roth, & Dement, 2005).

In a cohort study with 1207 young children Brunetti et al. (2001) found that snoring occurred occasionally in 15.8% of the children, while 4.9% of the children snored habitually. Obstructive sleep apnea was diagnosed in 9 children.

Parasomias Parasominas are defined as unpleasant and/or undesirable behavioural or experiential phenomena, which occur during sleep (Kryger et al., 2005; Thorpy, 2012). This includes different types of parasomias such as sleep talking, confusional arousal, sleep terror, self injuries during sleep, nightmares, dream enactment, and sleep related eating, for which prevalences are very different (Bjorvatn, Gronli, & Pallesen, 2010). Kotagal (2008) suggested in a review article that over 80% of all children experience some types of parasomia events. The most common ones in childhood are sleep terrors, sleep walking, and confusional arousals.

Sleep related movement disorder Sleep related movement disorders are characterised by simple and repetitive movements during sleep that disturb sleep quality. For instance periodic limb movement disorders or restless leg syndrome are typical diagnoses (Thorpy, 2012). Limb movement disorder is thereby described as repetitive, highly stereotyped limb movements that occur during sleep (Monderer, Wu, & Thorpy, 2010) while restless leg syndrome is characterised as the urge to move the legs (Earley, 2003). Periodic limb movement disorder in childhood has been linked to ADHD (e.g. Crabtree, Ivanenko, O'Brien, & Gozal, 2003). However, Crabtree et al. (2003) suggest that reduced REM sleep mediates this relation, which is common in those children, too.

Daytime sleepiness Young (2004) reviewed cohort studies and suggested that 1 in 5 adult suffers from daytime sleepiness. However, the term was often defined in different ways and therefore a clear prevalence rate cannot be given. Daytime sleepiness can be caused by many sleep disturbances listed above (e.g., insomnia) but also by short sleep durations, which is a common phenomenon in our western culture. In a study exploring risk factors in school-aged children Calhoun et al. (2011) found that in particular BMI percentile, waist circumference, heartburn, astma, parent-reported anxiety or depression, as well as sleep difficulties were related to daytime sleepiness.

2.2 Sleep and cognition

In this section, I will summarise literature on the link between sleep and cognition in adults and infants by mainly focussing on the role of sleep for memory and attention. In particular I aim to demonstrate that knowledge we have about the importance of sleep for cognitive performance in adults is not paralleled in the developmental literature.

2.2.1 Impact of sleep on adult cognitive performance

When describing the most important functions of sleep in section 2.1.2 I already addressed the crucial role that sleep plays for cognition in general. The two cognitive domains that appear to be influenced most are executive functionning or attention and sleep dependent memory consolidation. Therefore, I will focus on research that particularly addresses those two aspects in relation to sleep. There is a much larger body of literature underpinning this link in adults compared to infants. Studies relying on sleep deprivation or overnight research in sleep laboratories is usually only feasible with adults as participants.

2.2.1.1 Attention and sleep in adults

Attention is involved in most higher-order cognitive processes such as planning and learning, and different types of attention have been described. There is for instance sustained attention or vigilance, which is the ability to focus on a stimuli or task for a longer period of time. It describes a person's readiness to detect rarely occurring stimuli in an environment over a longer period of time. A second aspect of attention is the ability to shift attention from one stimuli to another called attention shifting. And a third attentional process is selective attention, which is characterised by a person's ability to focus on particular stimuli or features of a situation or task while neglecting others.

There exist several reviews and meta-analyses, which come to the conclusion that attention is affected by sleep deprivation (e.g., Van Dongen & Dinges, 2005; Banks & Dinges, 2007; Lim & Dinges, 2008, 2010). In general, chronic sleep restrictions are associated with lapses of attention (Banks & Dinges, 2007), although there are considerable individual differences in the vulnerability resulting from sleep deprivation (Van Dongen & Dinges, 2005). As already pointed out in chapter 2.1.2, sleep is crucial for maintaining the functional integrity of the fronto-perietal networks in the brain. Therefore, sleep restrictions are likely to impact sustained attention because these networks are weakened. Short-term and total sleep deprivation also triggered difficulties in both speed and accuracy over different cognitive tasks (Lim & Dinges, 2010). For instance, in psychomotor vigilance tasks, participants who had slept less slowed down, had higher error rates, and lapsed more for lengthy periods (Lim & Dinges, 2008). Furthermore, sleep-deprived people displayed greater variability in performance on attention tasks (Doran et al., 2001).

Moreover, habitual sleep is also related to performance on attention tasks. In one study, policemen differed in a psychomotor vigilance task depending on their sleep duration during the night prior to testing (Neylan et al., 2010). Furthermore, sleep fragmentation experimentally implemented made participants sleepier the next day and decreased their sustained attention even though their total sleep duration was as long as a control group who performed better (Martin, Engleman, Deary, & Douglas, 1996). Gumenyuk et al. (2011) compared performance in a change detection task in a group of people who habitually slept less than 6 hours with a group of people who slept 8 hours. Participants who were used to a shorter sleep duration did worse on the task, which was also mirrored by their EEG. In summary, these findings suggest that shorter sleep durations and more sleep fragmentation negatively affects attention in adults.

Attention is not only altered by sleep deprivation and influenced by habitual sleep, but it also related with attention deficits and ADHD, as demonstrated in a meta-analysis by Yoon, Jain, and Shapiro (2012). Sleep problems not only often occur in adolescents and adults with ADHD, but a diagnosis of ADHD was mistakenly given to people whose primarily problem resided in sleep disturbances. This suggests that it may be generally difficult to disentangle sleep and attention problems.

2.2.1.2 Memory and sleep in adults

So far, the largest proportion of the literature on the link between sleep and cognition has focused on the role of sleep in the context of memory consolidation (Carskadon & Dement, 2011, for review). There exist a number of hypotheses why sleep is particularly important for memory, which have been summarised in section 2.1.2: the Hyppocampal-Neocortical Dialogue Model and the Synaptic Homoeostasis Hypothesis. While the first one explains how new information is first stored in the hippocampus and then integrated in the neocortex during sleep, the second hypothesis describes how abstraction of newly learned memories take place by cutting down synapses.

In a meta-analysis of sleep and academic performance in students, Curcio et al. (2006) summarised that sleep quality and quantity were closely related to students' learning capacity. Frankland and Bontempi (2005) pointed out that a reorganisation of memory traces happens during sleep – memories that are first dependent on the hippocampus are later-on encoded in cortex. This explains why sleep is so essential for memory consolidation. Without it, this process would not occur and new memories would not get the chance to become permanent. Diekelmann and Born (2010) went a step further by discussing the different roles of slow-wave sleep and REM sleep in memory consolidation. They hypothesised that during slow-wave sleep memories are re-activated and re-distributed from the hippocampus to neocortex, whereas during REM sleep those memories are subsequently consolidated in cortex. In another paper, Diekelmann et al. (2009) reviewed articles on sleep and memory and drew the conclusion that declarative memory, which is more related to slow-wave sleep, already profited from short sleep periods, whereas procedural and emotional memory, which are more related to REM sleep, were found to be more dependent on sleep duration after learning. This led the authors to draw a general conclusion about the interaction of sleep and memory across development i.e., that children have a higher amount of slow-wave sleep than adults because they have a greater need to consolidate declarative memories.

In summary, those reviews and meta-analyses demonstrate that habitual sleep is important for memory. Nevertheless, even short sleep periods are beneficial for certain types of memory, e.g., declarative memory. For instance, when participating in a naturalistic spoken-language task, the linguistic contents were remembered less during the following awake hours but performance completely recovered after a period of sleep (Fenn et al., 2003). Moreover, the abstraction of linguistic rules from this language was facilitated even after a short nap (Lau, Alger, & Fishbein, 2011). In another study, Gaskell et al. (2014) also showed that a group of participants who napped after the language-learning task generalised their learning to new material; this did not hold for a group who did not nap. Furthermore, this effect was related to the amount of slow-wave sleep during the nap.

2.2.2 The link between sleep and cognition during development

In animal studies, sleep disruption early in life predicts later brain plasticity (Frank et al., 2001) and long-lasting learning deficits (Seugnet, Suzuki, Donlea, Gottschalk, & Shaw, 2011). In children and adolescents a recent review by Beebe (2012) summarised results regarding the consequences of poor sleep with respect to cognitive performance and behavioural functioning. In summary, it is crucial to detect and treat sleep problems early in life so as to avoid possible irreversible long-term consequences.

Although during the past decade, there has been an increasing interest in the link between habitual sleep and cognitive performance in infancy, the topic remains under-researched and there exist almost no longitudinal studies. Of course, infancy sleep research faces many challenges. Not only is it more difficult to measure sleep and cognitive performance reliably in infants and young children but also employing experimental designs and disentangling sleep effects from other factors is currently very difficult. Consequently, most studies have focused on measuring sleep alongside aspects of cognitive development, either concurrently or longitudinally, and simply report correlations between the two. Moreover, there are only very few developmental studies that include data from infants; most research has been done on adolescents, with some on children. This is certainly due to the fact that research on infants is more challenging and, for practical reasons, objective methods, such as polysomnography, are rarely employed. Also, a relatively high percentage of infant sleep research involves atypically developing infants such as preterm babies rather than the typically developing population. First, atypical research receives better financial support and second, these infants are under regular examination anyway, which makes it easier to record their sleep variables and collect data on their cognitive performance.

In the following chapter, I will first summarise the types of studies that have been so far used in the sleep and cognition research on infants in order to foster a better understanding of this research. Furthermore, as in the section on sleep and cognition in adults, I will describe findings relating sleep variables with attention, as well as studies investigating sleep and memory performance. Those two cognitive domains have been shown to be particularly influenced and related to sleep in adults. Therefore, it is likely that sleep also plays a crucial part in their development. Finally, I will give an outline of papers that focus on other aspects of infant cognitive functioning.

2.2.2.1 Study designs in the infant sleep and cognition literature

By and large regarding the methodology, one can divide papers on infant sleep and cognition into 4 groups. First, there are very few **experimental studies** that have been conducted and these have mainly focused on infants older than a year, predominantly with respect to the role of naps. For example, Gómez, Bootzin, and Nadel (2006) compared 15-month-old infants who had napped with infants who had remained awake, with respect to performance on a language learning task. Hupbach, Gómez, Bootzin, and Nadel (2009) used a similar design. The small number of experimental studies indicates how difficult it is to design them: not only is it more difficult the younger infants are and the more irregular their sleep is, also one has to be careful to control for confounding variables such as time of the day. Another type of study investigated **concurrent correlations** between habitual sleep and cognitive measures in the same infants. For example, Scher (2005) examined associations between sleep variables and scores on the Bayley Scales of Infant Development in a group of 10-month-old infants, and Lukowski and Milojevich (2013) investigated the relation between recall and sleep variables of the preceding week in the same age group. Those studies, however, often do not record sleep using objective measures such as EEG or actigraphy and rely on parent-report, which is biased, often overestimates the sleep duration, and does not reliably capture certain aspects of sleep variables, e.g., sleep fragmentation (Sadeh, 2011; Ashworth et al., 2013). The third kind of study used a **longitudinal design** where sleep was recorded early in development and related with cognitive performance later in life. A large proportion of those studies was done with atypically developing infants such as preterms (e.g., Beckwith & Parmelee, 1986; Whitney & Thoman, 1993; Gertner et al., 2002). The advantages of these longitudinal studies are apparent: individual trajectories of sleep as well as cognitive development can be studied, which enables more inferences than concurrent correlational studies. Finally, there are **theoretical papers** that review existing evidence and draw conclusions on the relation between sleep and cognition during development. For instance, Huber and Born (2014) discuss a possibly bi-directional link between slow-wave sleep and memory.

One big issue in studies investigating the link between sleep and other aspects of development is that it is challenging to disentangle sleep from maturation effects. In particular, correlational studies might just find significant associations between sleep and other variables tested because both can be explained by the maturational status of the child or any other third factor, which is influencing both. The only study design that can really control for this are experimental studies because effects can be led back to sleep variables in the sleep phase incorporated in the design. However, those studies do not examine the longitudinal association of sleep and other aspects of development but only take a snap-shot. Therefore, effects of sleep variables such as sleep problems, sleep duration, and sleep fragmentation, cannot be linked to long-term outcomes such as cognitive functionning. It is also not possible to disentangle maturational and sleep effects in longitudinal designs, too, because the maturational status of a child might be higher or lower than the mean at all the time points and might influence both, sleep and other test outcomes. Nevertheless, it is still possible to evaluate whether early sleep problems or other sleep variables are related to outcomes at a later point in time by controlling for those outcomes at T1.

2.2.2.2 Attention and sleep during development

Attentional biases and abilities play a crucial role during development because they influence how the infant filters incoming information and what s/he actually focuses on. This in turn determines what is perceived and learned. Attentional predispositions, such as a relatively automatic orientation, interact with genetic and environmental factors during development and shape later attentional abilities and cognitive performance (Scerif, 2010, for review). In a previous paragraph, I discussed the detrimental effects of sleep deprivation on attention performance in adults. The developmental question is whether sleep variables in infancy also have an effect on concurrent attentional abilities and can serve as predictor for later attentional performance.

To my knowledge, the relation between habitual sleep and attention has not been hitherto studied in infancy. One study by Lam, Mahone, Mason, and Scharf (2011a) reported positive correlations between longer night time sleep / less day time napping with the auditory attention span in 3- to 5-year-old children. Furthermore, there is one meta-analysis from Astill, Van der Heijden, Van IJzendoorn, and Van Someren (2012) that summarised studies on sleep duration in even older children between 5 and 12 years of age. In these age groups, sleep duration was not associated with measures of attention.

Whether there is also no link between other variables describing sleep variables, e.g., sleep fragmentation, and attention remains unclear. This question has so far only been addressed by research on infants / children with clinically recognised sleep problems.

One body of literature, for instance, investigates attention abilities in infants with sleep-disordered breathing or sleep apnoea. This is a relatively common condition in infancy, which leads to more frequent awakenings during the night. Therefore, studying it can be helpful to learn about the effects of fragmented sleep on cognitive performance (see, for example, Bourke et al., 2011). In fact, sleep apnoea may be related with attention-deficit disorders (Moldofsky, 2001) and may furthermore cause inattention (O'Brian et al., 2004) as well as hyperactivity (Melendres, Lutz, Rubin, & Marcus, 2004) in children. However, there is almost no evidence of studies using objective measures of attention, and in particular there is a lack of research on infants. Only one paper demonstrated that 4- to 8-year-old children with obstructive sleep apnoea show an altered event-related potential (ERP) in an oddball attention task (Barnes, Gozal, & Molfese, 2012).

Another body of literature concentrates on the link between attention-deficit / hyperactivity disorder (ADHD) and sleep. A systematic review from Cortese, Konofal, Yateman, Mouren, and Lecendreux (2006) summarised that children with ADHD are sleepier during the day, move more during night sleep, and are also more often diagnosed with sleep apnea. Very few studies have investigated the relation between sleep problems early in development and later emergence of ADHD or general attention problems. Thunstroem (2002) reported findings from a longitudinal study where 27 infants with chronic and severe sleep problems were followed up after 5.5 years. One quarter of those infants then met the diagnostic criteria for ADHD. Furthermore, O'Callaghan et al. (2010) found correlations between sleep problems in 6-month-old infants and attention problems assessed with the Child Behaviour Checklist at 5 years and sometimes at 14 years of age. One other study from Gregory, Van der Ende, Willis, and Verhulst (2008) also investigated this link between sleep problems and attention difficulties in older children. Those who reported less night sleep at 4 years of age were more likely to score higher on the attention problem scale of the Child Behaviour Checklist when they reached adolescence.

Sleep disturbances, however, occur more often in atypically developing populations and result in increased daytime sleepiness and cognitive performance (Carter, McCaughey, Annaz, & Hill, 2009; Annaz, Hill, Ashworth, Holley, & Karmiloff-Smith, 2011; Ashworth et al., 2013; Ashworth, Hill, Karmiloff-Smith, & Dimitriou, 2014b). The relation between attentional abilities and those sleep disturbances in atypical populations is only poorly understood. One study by Ashworth, Hill, Karmiloff-Smith, and Dimitriou (2014a) found that typically developing school-aged children presented better attentional performance in a Continuous Performance Task that was related to better sleep quality. This link, however, could not be found in children with William Syndrome or Down Syndrome.

Although the link between sleep and attention has been studied in adults extensively, there is a lack of studies on children and almost no evidence in infancy. Since most studies have investigated the relation between sleep problems and attention problems, we do not know whether habitual sleep in typically developing infants without sleep and attention problems actually influences their concurrent attention, e.g., their reaction time. However, it would be particularly important to know more about this natural link. If habitual sleep affects infants' attention on the following day, it is likely that their ability to learn is reduced. If this occurs for a prolonged period of time, this would probably have cascading effects on the infants' subsequent cognitive performance. Also, with respect to cognitive research on infants, it is vital to take into account the sleep of the preceding night or the actual sleepiness of the infant in order to avoid biases in task performance that simply stem from lack of attention.

2.2.2.3 Memory and sleep during development

Reviews on older children, adolescents, and adults suggest that sleep plays a crucial role for memory consolidation as well as for working memory (Curcio et al., 2006; Hill, Hogan, & Karmiloff-Smith, 2007; Graven & Browne, 2008; Kopasz et al., 2010; Gómez et al., 2011). However, the number of studies, which have been done on typically developing children, is small. In 2010, Kopasz et al. (2010) did a search aimed at identifying sleep and memory studies in healthy children and adolescents using the keywords "sleep", "memory", "learn", "child", "adolescents", "adolescence" and "teenager". Only 15 papers met the inclusion criteria. Those studies in general supported the evidence that sleep facilitates working memory and memory consolidation. In another review by Gómez et al. (2011), the authors focussed on the link between learning, memory, and sleep during development, but the studies on infants that they located only explored general cognitive development, not memory consolidation. Although sleep is highly important for memory consolidation, it is not clear whether different habitual sleep variables in typically developing infants actually make a difference to their memory abilities. A meta-analysis from Astill et al. (2012) failed to find a relation between sleep duration and memory performance in school-age children.

To my knowledge, there is only one study focussing on the relation between memory and habitual sleep in typically developing infants (Lukowski & Milojevich, 2013). The authors measured correlations between performance on an elicit imitation paradigm and parent-reported sleep variables from the preceding week. The percentage of nocturnal sleep was negatively and daytime naps positively related to memory. However, as mentioned earlier, parent-report measures do not capture sleep fragmentation reliably, yet examining the link between objectively measured sleep variables and memory is crucial. One study by Sadeh, Gruber, and Raviv (2003) investigated the effects of sleep restriction and extension in 10-year-old children in order to draw conclusions about the impact of habitual sleep on memory performance. One group of children was asked to reduce their sleep by one hour for 3 consecutive night, while another group was asked to sleep an hour longer each night. Sleep variables were monitored using actigraphy. Although the sleep fragmentation decreased in the sleep-restricted group, their performance on learning tasks got worse compared to the group who slept longer. These two studies suggest that habitual sleep variables actually play a role in memory performance and that investigating them more closely during infancy, when sleep variables are much more varied than subsequently, is very important.

Some studies investigated sleep effects experimentally, but only two of them were carried out on young children. Gómez et al. (2006) and Hupbach et al. (2009) tested memory consolidation in a group of 15-month-old infants who napped after being exposed to an artificial language as well as a group of infants who did not nap in between. Napping infants were subsequently better at abstracting implicit rules from this language, which suggests that sleep played an active role in memory consolidation. In one study on older children (9 to 12 years), word pairs were learned by a group in the evening and tested again on the following morning and the subsequent evening while, another group learned the word pairs in the morning and was tested in the evening and following morning (Backhaus, Hoeckesfeld, Born, Hohagen, & Junghanns, 2007). Retention of declarative memory was only increased after sleep, which also supports the hypothesis that sleep plays a crucial role in learning. Also in a study from Ashworth et al. (2014b) a group of school-aged children (6 to 12 years) performed a non-word learning task and the Tower of Hanoi cognitive puzzle before a period of sleep and subsequent wakefulness, whereas another group conducted the tasks before a period of wakefulness and subsequent sleep. Those children who slept after learning, but not those who were awake, improved in both tasks, which adds to the evidence that there is sleep-related learning during childhood.

2.2.2.4 Other aspects of cognition related to sleep during development

Most studies that investigated the relation between infant and child sleep and cognition have used parent-report measures as well as standardised tests such as the Bayley Mental Development Inventory (MDI). Generally, this body of literature suggests that fragmented and reduced sleep is associated with deficits in academic outcome, cognitive performance and IQ measures (Curcio et al., 2006; Ednick et al., 2009; Gómez et al., 2011). In a review paper, Maski and Kothare (2013) suggests that there is an association between the effects of sleep deprivation on core neural structures, e.g., the prefrontal cortex, and difficulties in executive functioning, emotional reactivity, and reward anticipation, which could result in academic struggles and decreased cognitive performance. A meta-analysis by Astill et al. (2012) reported correlations between habitual sleep duration and cognitive performance, executive functioning, school performance, and behavioural problems in school-aged children. Sleep duration was not related with IQ. Furthermore, Gregory and O'Connor (2002) found a longitudinal association between sleep problems at 4 years of age and behavioural problems in adolescence. However, infant studies on the correlation between cognition and sleep variables are again extremely rare.

In one study that includes measures on 10-month-old infants, sleep was assessed using actigraphy and sleep diaries, with parents also filling in the Ages & Stages Questionnaire (Gibson, Elder, & Gander, 2011). The authors found positive correlations between longer night sleep duration and sleep efficiency, with better scores in motor and cognitive development as reported by the parents. Another study investigated the link between habitual sleep and scores on the Bayley Scales in 10-month-old infants and found concurrent associations between sleep efficiency and general mental development (Scher, 2005).

Moreover, there is also some evidence that habitual sleep early in development can serve as an indicator for later cognitive development and mental age. For example, one study demonstrated that sleep variables on day one after birth were correlated with Bayley Scale scores at 6 months (Freudigman & Thoman, 1993). Several papers have pointed out the importance of sleep regulation during the first year of life. Dearing, McCartney, Marshall, and Warner (2001) conducted a study on typically developing infants where they assessed sleep variables at 3 different point in time between 7 and 36 months. Furthermore, they measured language and mental development in the older ages. Circadian sleep regulation at earlier ages was positively correlated with later cognitive development. Also Bernier, Carlson, Bordeleau, and Carrier (2010) demonstrated that better sleep regulation at 12 months was related to better executive functioning later in childhood. Another study on preterm infants found that with a more regular sleep variables at 32 and 37 weeks of gestational age, the infants scored higher in the Bayley Scales at 6 months (Gertner et al., 2002). Sleep predicted later development even better than the social environment assessed using the HOME Inventory. Finally, temporal organisation of sleep was also found to be related with later mental development in another study on preterm infants who were assessed at birth and at 6 months of age (Borghese, Minard, & Thoman, 1995) as well as in one study, which analysed sleep variables and mental development in premature infants at 7 time points over the first year of life. Finally, there is some evidence that sleep EEG and cognitive development are related. For instance, Becker and Thoman (1981) reported a positive correlation between the number of REM storms and mental development in very young infants.

In older children, sleep variables were shown to be related with academic performance. In a meta-analysis, Dewald, Meijer, Oort, Kerkhof, and Boegels (2010) found that sleep quality, sleep duration, and measures of sleepiness in older children and adolescents were related with school grades. Fallone, Acebo, Seifer, and Carskadon (2005) also examined this link experimentally by comparing teacher ratings on a group of children with restricted sleep with a group of children who slept longer. Children with less time in bed got higher scores on academic problems and attention ratings.

2.3 Sleep, Socio-Economic Status and Cultural Background

Sadeh, Tikotzky, and Scher (2010) summarised comprehensively the very board, interesting body of literature on parenting and infant sleep. They suggested a transactional model that incorporates a variety of factors, which influence infant sleep and vice-versa. The quality of infant sleep can be shaped by many factors and therefore this model is accordingly complex. It not only involves infant factors (i.e., constitution, health, temperament) and parent factors (i.e., personality, pathology etc.) but also the interaction between parent and child variables, e.g., concrete behaviours such as bedtime routines and soothing methods as well as broader characteristics such as attachment security and general emotional availability. Moreover, infant sleep, parent behaviour, and parent-child-interaction are embedded in a specific family background (i.e., family stress, number of siblings), in a specific environment (i.e., socio-economic factors), and in a culture with its specific norms and values. In this section, I shall only provide a short summary of the findings on infant sleep and the social environment that are likely to be relevant to the study described later.

2.3.1 Cultural background

Unsurprisingly, culture has an enormous influence on how a child grows up and also how parents deal with and evaluate infant sleep (Hiscock, 2010). In many African and Asian cultures, co-sleeping, i.e. sharing one bed with several members of the family, is the norm. In a US sample, co-sleeping and associated sleep fragmentation was dependent on cultural background (Lozoff, Askew, & Wolf, 1996). Also the socio-economic background of the family was found to moderate the link between sleep fragmentation and cognitive performance: in a high SES background, children with more night awakenings were less influenced in their cognitive performance than in a low SES background (Buckhalt, El-Sheikh, & Keller, 2007).

2.3.2 Parenting

Parenting behaviour at bedtime is a very controversial topic because the notion of what is "good" for infants depends on cultural values, individual beliefs, and many other factors. Moreover, it is a complicated variable to assess, since sleeping arrangements change constantly as the infant develops and gets older. In their review paper, Sadeh et al. (2010) drew the conclusion, that there is a bi-directional link between parental behaviours that influence the infants' ability to self-soothe and infants' sleep variables, which impact the strategies that parents adopt for an individual child. In general, increased parental presence at bedtime was found to have a direct impact on infant sleep quality, resulting in more sleep fragmentation (e.g., Adair, Bauchner, Philipp, Levenson, & Zuckerman, 1991). Also parental emotion and cognition about their child, i.e., concerns about their involvement at bedtime (e.g., Tikotzky & Sadeh, 2009) and parental psychopathology such as maternal depression (e.g., Stoléru, Nottelmann, Belmont, & Ronsaville, 1997) were related to infant sleep variables. Importantly, Sadeh et al. (2010) also point out that infant sleep problems can be a stressor for the family and a risk factor for maternal depression, for example. We need to keep in mind, however, that these relations are extremely complex and involve many different variables from the infant, the parent, and the specific interaction. For instance, a study by Weinraub et al. (2012) demonstrated an interplay between maternal depression, breast-feeding, infant temperament, and sleep fragmentation in the first 3 years of life. Finally, DeLeon and Karraker (2007) found that the interaction of parent-related and infant-related factors best predicted infant sleep fragmentation.

It is important to describe more closely the effect of **sleeping arrangements** on infant sleep since this is a factor that is also relevant in the studies described in this thesis. In general, there are three possible sleeping arrangements: co-sleeping, room sharing, solitary sleep, as well as a combination of these arrangements. Although co-sleeping is very common in many parts of the world and is definitely advantageous for many reasons, bed-sharing is related to increased awakenings (Sadeh et al., 2010). Mothers who bed-share are also more likely to breast-feed their infants, which again impacts on habitual sleep (Ball, 2003). Since breast-milk is digested quicker than formula, infants have a more frequent need of being fed during the night and consequently wake up more often. This is particularly the case for older infants (Elias, Nicolson, Bora, & Johnston, 1986). Mothers and infants who bed-share spend in general more time in lighter stages of sleep and less time in deeper stages of sleep compared to solitary sleepers (Mosko, Richard, McKenna, & Drummond, 1996; Mosko, Richard, & McKenna, 1997a). Moreover, they experience increased arousals. Bed-sharing has furthermore been associated with higher levels of marital stress and personal distress and is more often practised by depressed mothers. Teti and Crosby (2012) therefore suggested that co-sleeping could also serve as a marker for family stress in the Western world.

Apart from sleeping arrangements, **bedtime routines** also vary across cultures and families, influencing infant sleep quality. In a large national poll Mindell, Meltzer, Carskadon, and Chervin (2009) collected data on bedtime routines, sleep hygiene, and sleep variables. Across all ages, late bedtime and parental presence were associated strongest with poorer sleep quality, such as longer sleep onset latency, shorter total sleep time, and more night awakenings. The authors therefore recommended rules that parents should consider: children should go to bed without much intervention from the parents, should have an established bedtime routine that also includes reading, and should go to bed early. Fortunately, Mindell et al. (2011) demonstrated in another study that interventions can be effective and helpful to establish those rules: an internet-based intervention with 264 infants between 3 and 36 months of age was shown to improve the quality of sleep.

2.4 Summary

In this chapter, I reviewed the changes in sleep variables over developmental time as well as the important role of sleep for cognition in adulthood and infancy in particular for memory capacity and attention performance. Taken together, those findings suggest that infant sleep is related to aspects of cognitive performance – but many questions remain open. For instance, there is only a relatively small number of studies on typically developing infants without sleep problems. Moreover, many studies use parental report instead of objective measures of sleep. Also, it is still very difficult to define high quality sleep in infancy. The study presented in this thesis addresses those aspects.

Chapter 3

Methodology

In this chapter, I will describe the methods used in this study, namely the longitudinal approach, actigraphy, eye-tracking, and parent-report measures. Details on how those methods were applied in this thesis are reported in Chapter 4.

3.1 Longitudinal study designs

Longitudinal designs involve repeated assessment of the same variables over a period of time in the same participants. Longitudinal studies – in particular those which consider a range of different aspects of development and thus include various measures – are the most important instrument we have to study development. Only by knowing more about how individual differences manifest over time can we understand their importance, their interference, and how to device effective early interventions. It is the only method available to investigate change over time. Advantages of longitudinal designs involve the fact that intra-individual differences can be examined with respect to their trajectories. It is also possible to draw conclusions about the stability of characteristics within a person. Furthermore, the relation between different variables can be investigated concurrently and over time. In doing so, it is possible to predict outcome in one variable with outcomes in other variables collected at an earlier time point. However, longitudinal studies are often time consuming and expensive. Also, they normally have a certain drop-out rate that has to be considered in the statistical analyses.

3.2 Actigraphy

Actigraphy is based on the fact that there is more movement during wakefulness than during sleep. Actigraphs are movement detectors within a wrist-worn device that record and store gross motor movement data (see Figure 3.1 for an example). Amongst others, they are used during sleep periods to quantify sleep/wake patterns. In this context, levels of increased or decreased activity in the movement data are processed by algorithms in order to infer and calculate periods when the person was probably awake or asleep. Therefore, actigraphy is an indirect measure of sleep.

FIGURE 3.1: Image of an Actiwatch® 64 accelerometer from Philips Respironics Inc.

The gold standard for measuring sleep is polysomnography (PSG) described in Chapter 2.1.4.1. However, PSG has several disadvantages. First this method is labour intensive and very expensive due to the specialised equipment that is needed. Furthermore, it is mostly recorded for the duration of just one night because most of the time participants cannot stay connected to the devices during wakefulness when they want to move. Therefore, it does not reflect mean sleep-wake patterns over longer periods of time. Moreover, PSG is mostly recorded in a hospital setting because it can be challenging to install the equipment at the participants' homes. This, however, means that special populations, such as infants, who might be more sensible to changes of locations and resistant to instrumentation, might also show a different sleep-wake pattern than usual. An actiwatch, however, can be attached to a person for several weeks, allowing data acquisition for several consecutive nights and days. Actigraphy was validated in several studies with polysomnography and both measures were highly correlated with respect to their differentiating sleep from wake episodes in adults (Jean-Louis et al., 1996; Blood, Sack, Percy, & Pen, 1997; Sadeh & Acebo, 2002) and in infants (Sadeh, Acebo, Seifer, Aytur, & Carskadon, 1995; Meltzer et al., 2012). However, in infant validation studies, is was also shown that there is high sensitivity but lower specificity in actigraphy measurements (Meltzer et al., 2012). This means that the devices were normally very accurate in detecting sleep episodes but less accurate in identifying wake after sleep onset. Therefore, it has been suggested to always use actigraphy alongside other subjective or objective methods of sleep assessment.

The study described in this thesis employed the Actiwatch® accelerometer from Philips Respironics (see Figure 3.1). In a meta-analysis Meltzer et al. (2012) reported that it was the second most used actigraph device in infant research – at the time when the review was written, 52 studies (22.7%) had applied actigraphy.

The advantages of actigraphy in sleep research are that they can be worn 24 hours a day over a period of several days and nights without interfering with the participant's normal daily activities. In a study with children Paavonen, Fjaellberg, and Steenari (2002) showed that there was no difference whether the actigraph was placed on the ankle or wrist and most infant studies use the ankle (Meltzer et al., 2012). Furthermore, participants' sleep can be monitored at home; there is no need to use a sleep laboratory. This makes them particularly valuable in the study of special populations such as infants who cannot tolerate sleeping in a laboratory. Also, actigraphs are much less expensive than polysomnography. Those aspects make them more feasible in special populations, i.e., when testing atypical children, compared to other methods (see, for example, Ashworth et al., 2013, 2014a).

3.2.1 Hardware

The Actiwatch® 64 accelerometer from Philips Respironics as used in this study is a wrist watch-like device that can easily be worn during daily life. It contains an analogue system to detect movements. A piezo-electric beam detects movement on three axes and those movements are translated into digital counts that are accumulated across a pre-designed epoch interval (30 seconds in this study) and stored in the internal memory. The memory capacity of the Actiwatch is sufficient to store movement data for several weeks.

3.2.2 Software

In this study, I used the Software Actiware Version 5.61 for Windows together with an ActiReader that could be attached to a PC with a USB cable. Each actigraph was configured before I handed it over to the parents. During the configuration process the participant number was stored in the device for later identification. Also the time zone, the period that should be recorded, and the epoch length (30 seconds) were determined. After the week of data collection, I connected the Actiwatch to the computer using the ActiReader and downloaded the data into a database. Using the Actiware Software, I selected the nights where data had been collected and exported the data into a csv-file. Although it is possible to process the data using the Actiware Software in order to code sleep and wake periods as well as to calculate the common sleep variables (sleep duration, number of night awakenings and such), I decided to reprogram the scoring algorithm in Matlab. The Respironics Customer Service kindly agreed to send me details of the algorithm, which is also reported in Kushida et al. (2001). This not only allowed me to quickly merge data and try different settings, but also enabled me to reject nights with specific criteria (e.g., nights that did not start with an awake period because parents had forgotten to attach the actiwatch in time, or nights with a sleep period that was shorter than 2 standard deviations of the sample mean).

The algorithm takes into account the epoch to code as well as the preceding and following 4 epochs using different weightings. Figure 3.2 provides an example of the coding processes of one epoch that is extracted from an actigram, i.e., the visual display of the epoch scores over time. In this example, the score of the epoch to code is 48 (the orange epoch in the figure). The epoch to code is weighted double, the 4 directly preceding and following epochs are weighted by 0.2 (blue epochs in the figure), and the remaining 4 epochs are weighted by 0.04 (green epochs in the figure). All scores are hence multiplied by their corresponding weights and the obtained values are summed. In the given example, the calculated value is 107.04.

There are four thresholds inbuilt in the Respironics ActiWare for coding the calculated epoch ratings into 'wake' and 'sleep'. If the calculated epoch score is greater than the threshold, the epoch is coded as 'awake'; if it is less it is coded as 'asleep'. There is a low threshold at 20, a medium threshold at 40, and a high threshold at 80. In the given example, the calculated value is larger than all thresholds and therefore would in

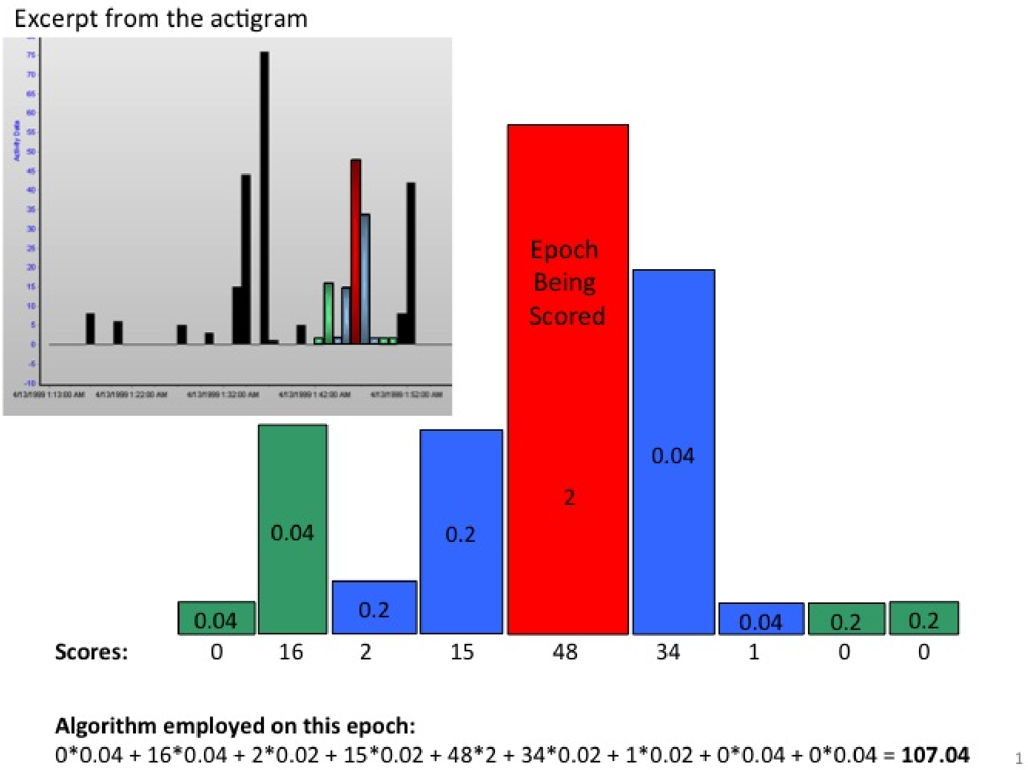


FIGURE 3.2: Illustration of the actigraphy coding algorithm using as example one random epoch.

any case be coded as 'awake'. Furthermore, it is also possible to define an automatically computed threshold using the data of the particular study. This automatic threshold is the mean of the scores in the study multiplied by 0.444. I choose to work with the automatically calculated threshold in order to compensate for differences between ages. After coding, each 30-second epoch is either defined as 'awake' or 'asleep'. Further data manipulation, such as calculating the total sleep duration or sleep fragmentation, was done in Matlab and will be described in Chapter 5.

3.3 Eye-tracking

Eye-tracking was first used in the 19th century by Lamare and Hering, who observed and described the movements of the eyes during reading (Wade, 2010). Through the invention of video recordings, it was later possible to re-examine eye movements retrospectively. In the last decades, eye-trackers with in-built infra-red diodes became increasingly accurate and easy to use, such that nowadays it is unnecessary to code eye movements manually.

The measurement of eye movements is a powerful tool for investigating perceptual and cognitive functions in both infants and adults. In pre-verbal infants, looking is a major gateway to the developing brain (Gredeback, Johnson, & von Hofsten, 2010). It is particularly advantageous in developmental research since it allows implicit non-verbal data collection. Although looking patterns do not directly reveal information about brain functioning and real time neural computations, they still make it possible allow to draw conclusions about what a child is processing. Hitherto, the majority of infant studies employed preferential looking, familiarisation, or habituation paradigms, where looking times were coded and inferences made as to whether infants were able to make discriminations (Aslin, 2007). Aslin (2007) therefore stated that "It is no exaggeration to say that without looking time measures, we would know very little about nearly any aspect of infant development". Eye-tracker are consequently very handy – they make the process of recording, assessing, and analysing these looking time data much more precise. Moreover, they enable researchers to define areas of interest and investigate looking durations towards them. But there is more that can be gained from eye-tracking (Aslin, 2011). It is not only possible to examine looking time durations but also the macro- and micro-structure of looking patterns. These are, for instance, fixation durations, patterns of fixations, number of saccades, saccade latencies, and directions of saccades.

3.3.1 Hardware

The Tobii X120 together with a normal 17-inch monitor screen on which visual stimuli are projected was employed in this study. The eye-tracker was placed underneath the screen on a table in front of the seat where parents and infants sat while watching the presentations. The eye-tracker was connected to a Mac computer with a LAN cable, which was also linked to the screen. A small camera (Logitech QuickCam Vision Pro) was attached to the top of the screen in order to record the infant's face while watching the procedure. Tobii eye-trackers use infra-red diodes to generate reflection patterns on the corneas of the infant's eyes. Those lights are invisible to the participants and therefore do not distract their attention. Image sensors in the eye-tracker collect these reflection patterns and estimate the gaze direction using an algorithm (the Tobii eye-tracker uses the first and forth Purkinje Image for this eye gaze estimation). Gaze directions of both eyes are calculated separately. The Tobii eye-tracking system is particularly useful in infant studies as it allows for a reasonable degree of head movement, while children sit on their parent's lap.

3.3.2 Software

In a first step, I always adjusted the set-up of eye-tracker and screen and measured parameters that described their position with respect to each other, such as the eye-tracker angle, the distance between eye-tracker and screen, and the screen angle and display area. Those measurements were then entered into a configuration tool provided by Tobii (Tobii EyeTracker Browser).

Throughout the testing procedure, I used ScreenFlow to recorded the screen where the eye-tracking tasks were displayed as well as the face of the infant. I did this to be able to identify retrospectively periods of inattentiveness and distinguish them from periods, in which the eye-tracker was not recording properly despite the infant watching the scene.

For all further processes such as calibration and testing, I used Talk2Tobii, which is an interface between the Tobii eye-tracker and Matlab. With Talk2Tobii it is possible to program contingent eye-tracking paradigms and more flexible testing procedures.

At the beginning of each testing session, a calibration was done to ensure that the eye-tracking algorithm to estimate gaze direction was tuned to the infant's eyes. First, infants saw a short movie clip with a dancing elf while I adjusted the distance of the infant from the monitor as well as the height of the infant's head with respect to the screen. Two green dots on the screen indicated when the eye-tracker actually captured the reflections of the corneas. If those dots were in the right position (centre of the screen), I started the calibration procedure. During calibration the infant's attention was attracted by five dots coming up at various locations on the screen presented together with a funny sound while the eye-tracker was calculating the gaze direction. This calculation was then matched to the actual location of the presented stimuli. Calibration was only repeated if less than 4 of the 5 dots were accurately calibrated.

The paradigms and test procedure were programmed in Matlab and Psychtoolbox. For each test run, the raw data of the eye-tracker was stored in the computer as the x- and y-coordinate of the right and left eye as well as time in milliseconds. Moreover, I programmed scripts that stored data from each paradigm separately on the computer in different ways. For instance, sometimes data for each trial in a paradigm were stored on their own, or looking times to areas of interest / saccade latencies were calculated during testing and saved in another file.

3.4 Parent-report measures

Two questionnaires, one on sleep and one on the infant's general development, as well as a sleep diary were employed in this study. Parent-report measures are a feasible and quick method of assessing aspects of infant development. However, they should be interpreted with caution since different parents may estimate their infants' development in different ways. For instance, there is satisfactory agreement between actigraphy and sleep diaries when parents estimate their child's sleep duration, but not for variables related to sleep fragmentation (e.g., Werner et al., 2008). The sleep questionnaire and sleep diary employed in this study will be described in Chapter 5 whereas details about the questionnaire on general development will be given in Chapter 7.

Chapter 4

Study Design, Participants, Materials, and Procedure

4.1 General study design

The study had a longitudinal cross-sectional design and a sample size of 40 infants. Sleep measures were taken for 7 consecutive nights using actigraphy and sleep diaries when the infants were 4, 6, 8, and 10 months old. This constitutes one thousand one hundered and twenty nights of infant sleep data. Subsequently infant and caregiver visited the research facilities in order to participate in a battery of eye tracking tasks on number processing, attention, and memory. Every other month, parents also filled in questionnaires on infant sleep and general development.

4.2 Participants

To investigate the relation between sleep and cognition in infancy this study focused on the age range 4 to 10 months. Four months were taken as the start age for two main reasons. First, it is very difficult to test younger infants using eye-tracking because of bad calibration due to watery eyes and shorter overall attention spans. Second, sleep patterns are more established at 4 months than in younger infants and drawing meaningful conclusions about the relation between sleep and cognition is more feasible. Moreover, it makes sense to start a longitudinal study when infants are 4 months old because families had time to get used to the new situation and parents usually feel more comfortable in predicting the best times for their child to be tested. Twelve months were taken as the end point because after that age infants tend to get inattentive much quicker, paradigms would not work anymore for older infants, and also due to feasibility aspects that a 3-year PhD project dictates.

Ethics were approved by the Ethics committee of the Freiburg International Ethic Committee, Germany (FEKI) and the study was insured by Hahnenberger Versicherungen. Because the study was conducted in the research facilities of Procter & Gamble Innovation Centre in Schwalbach, Germany, a thorough and comprehensive process was required including a long and detailed report of the study aims, design, procedure, participants, data handling and participant identification, as well as an outline of the planned analyses with power calculations. This report also needed to be approved by Procter & Gamble and signed by several employees from the company.

All infants tested were drawn from the existing consumer panel list database of Procter & Gamble's research facilities in Schwalbach, Germany. This list consisted of parents who signed up before or shortly after the birth of their child in order to take part in on-going studies on nappy quality and consumer satisfaction. Parents of 2- to 3-month-old infants who had signed up for participating in studies were called twice about a month prior to the start of the longitudinal study. In the first short call they were very briefly informed about the longitudinal study and asked whether they were in general interested in taking part. In the second and longer call I explained the aim and procedure of the study in detail and answered questions. All parents were still eager to participate and were invited for an initial information meeting. This meeting lasted about one hour and took place at the research facilities. Parents received a sample copy of all the study documents and read through it together with the experimenter. This was done to avoid misunderstandings and errors in completing the questionnaires. Furthermore, I explained in detail the usage of the actiwatch, what it measures, and how this relates to sleep. Finally, I described the eye-tracking procedure giving examples and showing pictures. At the end of the meeting, parents received two copies of the informed consent form that needed to be signed by both parents before the start of the study. The informed consent statement explained the study in detail, including the purpose of the study, the test design, any test measurements, risks and benefits of participating in the study, compensation and payment schedule for participating, and an explanation of the participant's right to withdraw from the study. In addition, the form gave the parent information about confidentiality of the data. The informed consent was given in German and can be found in Appendix A.

Parents also needed to sign a short questionnaire in order to make sure that inclusion/exclusion criteria were understood and followed. Inclusion criteria were:

1. Informed consent needed to be dated and signed by both parents.
2. The infant is 3-4 months at the beginning of the study.
3. The child is generally healthy.
4. The parent is aware of the longitudinal design and willing to stick to the study instructions.
5. The child is not born preterm.

Exclusion criteria were:

1. The infant is not diagnosed with a chronic condition or medical illness that could effect the outcome of the study or could harm the infant though the participation of the study.
2. Hearing or seeing is impaired.
3. The child does not participate in any other study that could impact on the outcome of this study.

To compensate for their participation parents received 20 Euros at each visit as well as free nappies for the duration of the study.

Forty infants (21 females) with an average of 16 weeks and 2 days (age range: 14 weeks - 18 weeks) were included in the final sample of the initial testing at Time 1 and subsequently followed up every 4 weeks. Families had a caucasian background and lived in the Frankfurt-area. One mother was a single parent; in the other families mother and father lived together in one household. In 4 cases, fathers and mothers were equally involved in care-giving and in 2 cases the father was a stay-at-home parent. Regarding their highest educational degree, 9 mothers had a university degree, 21 had gone to college (German

Fachhochschule), 10 had a certificate from secondary school (German Realschule), and 1 a high-school diploma (German Hauptschule). Fathers' highest degree was similarly distributed with 9 having a university degree, 20 a college degree, 4 a secondary school certificate, and 7 a high-school diploma. The highest degree of mothers and fathers was significantly positively correlated, $r = .36$, $p = .02$. Fifteen of the participating infants were first-born, 21 had one older sibling and 4 had two siblings.

Data were not collected from one infant at 8 and 10 months because of illness and from another infant at 10 months since the family had moved away in the meantime. Furthermore, at each testing point and for each measure, some data are missing from some infants because they did not complete the testing procedure due to fussiness or because they failed to look at the monitor. The exact sample sizes for each test, condition, and age group are reported in the result sections for each measure respectively.

4.3 Apparatus and materials

Each testing phase of the study comprised four parts: eye tracking tasks, observation of parent-child-interaction (PCI, this was only done between eye-tracking tasks when infants needed a rest and is not part of the analyses in this thesis), questionnaires, and sleep measures.

4.3.1 Sleep measures

The **Actiwatch® accelerometer** (Philips Respironics) is a miniaturized computerized wrist watch-like device that monitors and collects data generated by movements (see Chapter 3). Parents were asked to apply an actigraph on their child's ankle for 7 nights, every 2 months, prior to the infants taking part in the other tests at the lab. The device was attached nightly before bedtime, and removed in the morning. I asked parents to apply it on the left ankle with loose pants or a sock placed over the actiwatch to protect against accidental removal by the infant.

Furthermore, the parent was given a **sleep diary** to record a summary of sleep / wake periods. The sleep diary also contained questions about the time at which they made each nappy change or fed during the night, as well as on the health status of the infant. Details about the sleep diary are given in Chapter 5.

4.3.2 Eye-tracking Tasks

This study tested performance in short-term memory, attention and disengagement, as well as number processing in order to relate outcomes to sleep variables in infancy. Memory consolidation as well as attention are the cognitive processes mostly linked to sleep (see section 2.1.2 and 2.2).

Short-term memory was chosen because of the described importance of sleep for memory consolidation that has been found in studies on adults (Carskadon & Dement, 2011, for review) and older infants (Gómez et al., 2006; Hupbach et al., 2009). Therefore, it can be hypothesised that sleep variables would also relate to memory abilities in infancy. In the context of this PhD project, it was not feasible to test infants twice at one age in order to assess sleep dependent memory consolidation as in studies of Gómez et al. (2006) and Hupbach et al. (2009). Those designs incorporate a training phase, an intermediate sleep phase, and a testing phase in order to examine how sleep quality and quantity affects memory processes. As already pointed out earlier, it is very challenging to implement similar designs in infants – actually those studies looked at 15-month-old toddlers – because of variable sleeping patterns and practicality issues. In this PhD project, I therefore focused on the relation between sleep and short-term memory tested at one point in time. By this, I wanted to assess individual differences in general memory development and relate them to sleep variables.

Attention was included as a measure because of its function for learning and cognitive performance in general (Scerif, 2010, for review). If sleep related to the ability to attend to and disengage from stimuli, sleep difficulties early in life could have detrimental effects for further cognitive development. As described in section 2.2, there are several types of attention. I choose to focus on attention shifting abilities, i.e., visual attention and disengagement, in my PhD project. Firstly, it is more difficult to find tasks that test selective attention during the first year of life and that can be employed in 4- to 10-month-old infants. Second, having already an extensive test protocol, a task to examine sustained attention or vigilance would be impossible to conduct because it would have been much more time consuming.

Number processing was chosen as third measure. Numerical sensitivity is considered to be a cognitive domain – a core knowledge common to human beings and many animal species – that changes in predefined patterns (e.g. Gelman & Gallistel, 2009; Spelke & Kinzler, 2007). Cognitive domains other than cognitive processes are controlled by specialised modules. This means that those domains should be independent from other cognitive abilities or also sleep variables. I would like to test whether number processing is really a separate module that does not relate to other aspects of development.

All eye-tracking tasks were programmed with Matlab 2010 and Psychtoolbox (MathWorks, Natick, Massachusetts) and were presented on a 17-inch computer screen. A Tobii X120 eye-tracker (Tobii, Stockholm, Sweden) was used at 120 Hz during the eye tracking tasks to record infants' looking patterns. Sounds were played through two external stereo speakers. During all eye-tracking tasks infants were seated on their caregiver's lap while watching stimuli on a screen. An eye-tracker recorded gaze behaviour. During eye-tracking the infant's face was video recorded by a camera (Logitech QuickCam Vision Pro) attached on the top of the eye-tracking screen. This was done so that the experimenter could assess the infant's alertness while testing as well as review the recording at a later point in time to make judgements about the state of the child and whether the data should be included in the final analyses. The tasks are described in greater detail in later sections of this thesis and are therefore only briefly presented here.

Several conditions of a **number discrimination** task were designed. Firstly, small number discrimination was tested in infants at all ages using a familiarisation paradigm. Infants were familiarised to two images of either 2 or 3 dots next to each other during a familiarisation phase and were then presented 2 and 3 dots side by side during a testing phase. Looking times to either of the numbers indicated whether infants discriminated and were able to detect the 'new' number. Secondly, I tested large number discrimination with 8 vs. 16 in the 4- and 6-month-olds, 8 vs. 12 in the 8-month-olds, and 8 vs. 10 dots in the 10-month-olds using the same paradigm. The different ratios reflected what is known about number sensitivity in infants. The **gap-overlap task** evaluated the ability to disengage from a central stimulus to a peripheral one by measuring saccadic reaction time in three conditions: there is a gap between the presentation of the central and the peripheral stimulus, or there is no gap, and or there is an overlap between the two (see Elsabbagh et al., 2009). For the **memory measure**, I included a task adapted from

Richardson and Kirkham (2004). All eye-tracking tasks will be described in detail in Chapter 5 8,, 9, and 10.

Between, and after, the small and large number condition of the numerical discrimination task, the gap-overlap task, and the memory task, infants watched short child-friendly clips from 'Sesame Street' and 'In the Nightgarden' in order to maintain their attention and give them a break.

4.3.3 Questionnaires

At the beginning of the study, parents were asked to answer some **general questions** on the gender of the infant, the socio-economic-background of the family, and the number of siblings (see Chapter 6).

At each time point, parents filled in a translated version of the **Brief Infant Sleep Questionnaire** (BISQ, Sadeh, 2004). The BISQ is a 13-item survey assessing night and day sleep duration, night awakenings, infant's sleeping location, position, and schedule, as well as methods of falling asleep during the past week. The questionnaire was validated using sleep diaries and actigraphy and showed high test-retest reliability ($r > .82$) (Sadeh, 2004). In addition, I included one question on the evening ritual and 6 questions on parent sleep and experience when taking the infant to bed. Results of this questionnaire are reported in Chapter 5.

Moreover, parents completed an age-appropriate part of the **Ages & Stages Questionnaire** (Squires, Twombly, & Diane Bricker, 2009) described in detail in Chapter 7. It covers five aspects of infants' general development each containing 6 questions: communication, gross motor, fine motor, problem solving, and personal-social development. An example question is: 'While your baby is on her back, does your baby bring her hands together over her chest, touching her fingers?'. Possible answers are 'yes', 'sometimes', and 'not yet'. The questionnaire has high test-retest reliability (94%) and has been validated with the Revised Gesell and Armatruda Developmental and Neurologic Examination and the Bayley Scales of Infant Development (Squires, Bricker, & Potter, 1997; Schonhaut, Armijo, Schonstedt, Alvarez, & Cordero, 2013).

4.4 Procedure

Parents were given detailed information on the study during the first meeting before they signed the informed consent. They received a sample copy of all the study documents, i.e. the Ages & Stages questionnaire for the 4-month-old infants, the BISQ, and a sleep diary, and the experimenter made sure that the procedure and requirements were understood. Moreover, parents were familiarised with the actiwatch. They were asked to attach the device at the infants ankle in the evening before bedtime (e.g. with the last nappy change) and to cover it with a sock to avoid it falling off during the night. Parents could remove the actigraph in the morning when the infant was fully awake. A first appointment was arranged with all parents who were eager to participate after this information session. If parents had not handed in the informed consent before, they were asked to bring it to the first appointment.

Every two months, families received an envelope with the actigraph, a sleep diary, as well as a copy of the Ages & Stages Questionnaire for the current age and the BISQ about 10 days before they had the appointment at the research facilities. Furthermore, they again received instructions on the use of the actiwatch and were asked to apply the device for 7 consecutive nights as well as to fill in all documents. Every other month, they received the Ages & Stages Questionnaire and the BISQ via email or per post and were asked to fill them in the following week. Appointments for the visits were scheduled for between 8am and 4pm and took at least one hour. When arranging them about 12 days in advance, parents could comment on the current daily rhythm of their child and I always arranged a time that suited parents best and took account of babies' nap routines in order to increase the probability that the infant was in a good mood for participation.

At the beginning of each session that took place in the P&G GIC Consumer Area at Schwalbach Technical Center in Germany, parents returned the Actiwatch along with the sleep diary and completed questionnaires and I checked that everything was filled in. Also, I asked questions regarding any change in health status of the child. The infant was then familiarised with the experimenter (me) and the lab setting for about 15 minutes. The whole testing procedure took place in the same room (see Figure 4.1: photo from one corner of the room with the PCI seting on the right hand side and the eye-tracking setup on the left-hand sinde).

FIGURE 4.1: Photo of the room where all the testing took place.

Then the infant was seated on the caregiver's lap about 50 cm away from the eye tracker and the screen. The set up was surrounded by black curtains so that the infant's attention was not distracted, with the experimenter monitoring the protocol from behind the curtain. A 5-point default-calibration was used, where interesting balls popped up on each screen location together with an interesting noise. Calibration was repeated if inaccurate. Then, the first numerical sensitivity task for large numbers started, followed by a short video clip, and then another numerical sensitivity task for small numbers. Subsequently, the infant was presented with a first round of the attention task (gap-overlap), the memory task, and a second round of the attention task. In between tasks, more short video clips were presented (e.g., from Sesame Street). If the infant showed signs of fussiness or boredom, the eye-tracking procedure was interrupted and only continued after a short break. Otherwise, the eye-tracking tasks were not shown for longer than 12 minutes. After another short break and re-instalment of the setting for the PCI recording, I asked parents to play with their infant on a blanket as they normally do at home for a maximum of 10 minutes. During the play session, I left the room and monitored it from behind a one-way mirror. If the infant was still attentive and seemingly happy to proceed after the interaction, the eye-tracking procedure was repeated once again after a short break. At the end of each testing session, parents received 20 Euros as well as nappies for the following month. The complete procedure for a whole visit is illustrated in Figure 4.1.

4.5 Pilot Studies

In order to develop a battery of tasks that investigates different aspects of cognitive development in young infants, I started piloting in January 2012 and tested in total about 60 babies. All eye tracking tasks were conducted on a Tobii T120 in the Birkbeck Babylab, University of London, and programmed with Matlab using Talk2Tobii. The first babies coming in for piloting only participated in a numerical discrimination task. So far, most studies that tested numerical sensitivity used a habituation paradigm. Exceptions are, for instance, a preferential looking task employed by Libertus and Brannon (2010) in 6- to 9-month-old infants or a multi-model task designed by Izard, Sann, Spelke, and Streri (2009) to test newborns. Therefore I first adapted the design described by Xu (2003). In a first run, infants were habituated to a certain number depicted as black dots on a computer screen (e.g. 32). As soon as the infants looked away for more than 2 seconds, a central attractor and a noise redirected the infant's attention to the screen where the next trial started and a novel set of objects with number remaining constant was presented. Habituation phase ended as soon as the infant had looked less than 50% of the time at the presentation for 3 consecutive trials compared to the first 3 consecutive trials of the experiment or after a total number of 14 trials. The consecutive test phase lasted 6 trials and alternately infants were presented with a novel (e.g. 16) and the familiarised number. In the course of piloting I ameliorated the matlab program to avoid crashes. Furthermore, I was concerned about the attractiveness of the task. My aim was to assess small and large number processing in the same infants but for most of the piloted infants, I could only show one run of the task before they got tired. Habituation paradigms work by boring the participant before showing a new stimulus. Therefore, infants were mostly not interested in watching the task twice. Consequently, I changed several aspects of the procedure to increase the infant's attention during the test trials:

1. Different shapes were used within the task (not only dots but also triangles and squares).

2. The objects were presented in colour.

3. I determined the trial length during piloting (10-18 seconds per trial) to shorten the task.

4. Objects moved suddenly every 2 seconds to attract the infant's attention (a similar manipulation is described in Izard et al. (2009)).

On the one hand, these arrangements met the objective that the infants were more vigilant during the test trials so that the obtained eye-tracking data were usable for more than one test run. On the other hand, however, infants failed to meet the habituation criterion as they were too interested in the task during the habituation phase. Therefore, I decided to change to a preferential looking / familiarisation paradigm. For this, I presented one number to the infants for a predefined number of familiarisation trials with a predefined trial length. During test trials, I then presented them two different numbers (one familiar and one new number) next to each other while recording looking times to either side. I tested the following alterations:

1. Trials lasted 5 to 10 seconds each in order to determine the shortest possible test duration without modifying the results.

2. I used 5 to 10 familiarisation trials.

3. Different shapes and colours were used.

4. During familiarisation, infants saw single as well as paired stimuli.

5. Large number discrimination was tested with 16 vs. 32 and 8 vs. 16 objects.

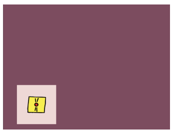
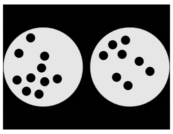
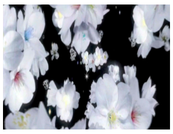
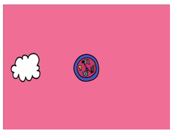
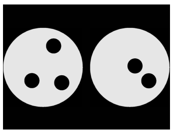
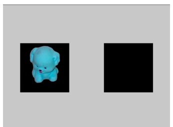
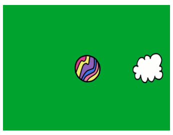
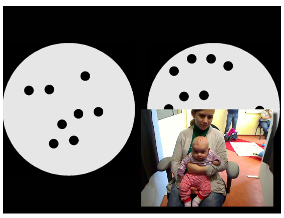
6. Infants were presented with one and two test trials.

I piloted several 4- to 12-month-olds and analysed the data to check whether the paradigm would work. A two-factorial ANOVA was calculated to test whether the percentage of looking time to the new number was significantly greater. The first factor was the 'Side of Interest' indicating whether the new number was presented on the side or not. The second factor was 'Side of the screen' (right vs. left). Beforehand only the percentage of looking time per side was calculated and trials with very little general looking time were eliminated. Regarding small numbers (2 and 3), infants looked in general longer to the new number in the first test trial, $F(1, 33) = 2.96$, $p = .09$. Infants older than 6.2 months successfully discriminated 8 from 16 when being familiarised with 8, $F(1, 31) = 3.48$, $p = .07$, but there were no significant results for large number discrimination when they had been familiarised with the larger number, $F(1, 19) = 26.31$, $p = .83$.

Nevertheless, I decided to familiarise with both numbers in the longitudinal study to examine this effect since it had hitherto never been assessed in the same infants nor longitudinally. As expected, large number discrimination was not significant when also taking into account infants younger than 6 months, $F(1,37) = 0.13$, $p = .72$. This suggested that only older infants were able to differentiate 8 and 16. There was a small difference between familiarisation with a single stimulus and with two stimulus next to each other (paired) – the latter being slightly more significant. Therefore, I decided to show paired familiarisation stimuli.

The other two eye tracking tasks, the gap-overlap task and the memory task, were introduced during and ameliorated in the course of the piloting phase. Both tasks have previously been used by researchers at the Birkbeck Babylab and were adapted for this study. During piloting, I made sure that all data were stored correctly and programmed an on-line coding for the gap-overlap task. Also, some German and English parents filled in a German or English version of the questionnaire used in the final study about their infant's sleep habits, length, pattern, routine etc. I interviewed them to detect any difficulties or ambiguous questions, but nothing came up.

Table 4.1: Complete procedure of a normal visit.

Welcome	**about 10 minutes**
	Welcoming parent and infant; collecting the questionnaires / diaries and the acti-watch
Eye-tracking	**7 - 12 minutes**
 	Calibration: finding the eyes and picking up fixations at 5 points on the screen
 	Large number task followed by a short video clip
 	First half of the gap-overlap task followed and interrupted by short video clips
 	Small number task followed by a longer video clip (55 seconds)
	Memory task
 	Second half of the gap-overlap task followed and interrupted by short video clips
Parent-Infant-Interaction	**about 9 minutes**
	Interaction with toys
Eventually more eye-tracking	**about 8 minutes**
	If possible, more eye-tracking data was collected following the same order as in the first round

Chapter 5

Sleep Patterns over Developmental Time

Three different methods to assess sleep pattens longitudinally in infancy were employed in this study: a sleep diary, actigraphy, and a sleep questionnaire. The sleep diary and actigraphy were used at 4, 6, 8, and 10 month for a week. The questionnaire was filled in by the parent every month. In this section, I will first describe all methods in detail and how data were coded and extracted from them. Then, I will give an overview of the extracted sleep variables and narrow them down to a few that will be used in the rest of this thesis' analysis.

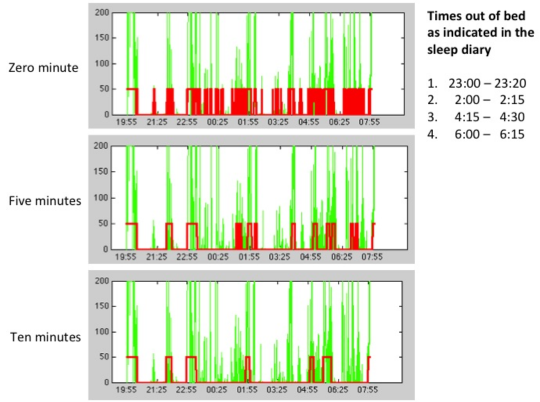
5.1 Methods

5.1.1 Sleep diary

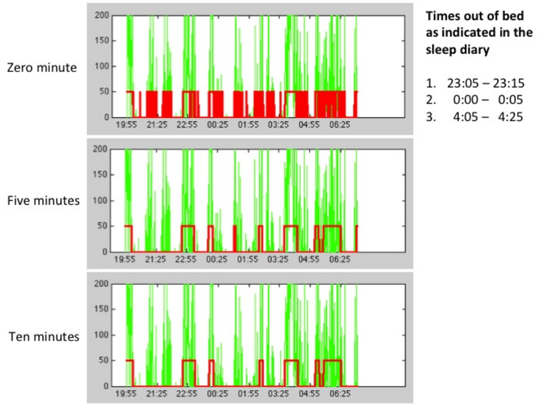
The sleep diary in this study was used as a record of an infant's sleeping and waking times that helped to code the actigraphy data and eliminate nights when the infant was ill or the actigraph was not attached properly. In the version employed in this study, parents filled in the times when they laid their infant into the bed in the evening and the times when they took him/her out of bed in the morning. Also, they indicated whether the actigraph was attached to the infant's ankle throughout the night. In a few cases the actigraph had fallen off and those nights were excluded from further analyses. Moreover, parents were asked whether this was a typical night for their infant and whether there was any change in the infant's health status. There was enough space to describe in detail why this night was not typical and what changes there were. This was done to make sure that no abnormal nights because of illness or a different sleeping arrangement (e.g., family holidays or long car drive) would bias the analyses. Finally, parents were asked to write down the times when they took their infant out of bed during the night in order to feed or change nappies. I changed the diary once slightly in the course of the study. While at first I only asked about night sleep variables, I then added questions about day sleep when the infants were 6 (for 11 infants) or 8 (for 29 infants) months old. In this later version, parents were also asked to indicate when their infant fell asleep during the day and woke up again, in order to collect data on napping variables. An English translation for one day of this version can be found in Appendix B.

5.1.2 Actigraphy

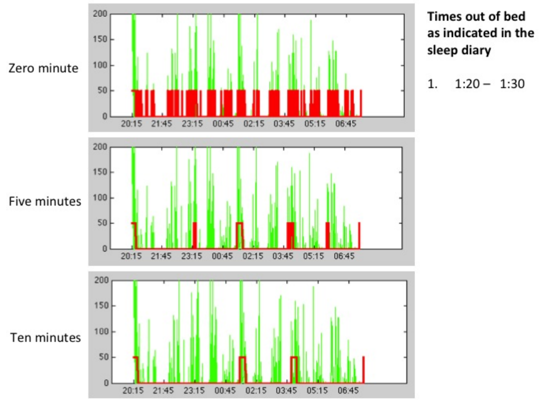
A priori of coding and analyses, I selected the nights that met inclusion criteria using the Actiware Software described in Chapter 3. That means that I did not select any nights in which the infant was ill or sleep was disturbed or altered by other factors. For the 'normal' nights as indicated in the sleep diary, I extracted only data within the boundaries using the times written down by the parents. Each 30-seconds epoch of this selected data was coded into 'awake' or 'asleep' as previously described in Chapter 3. Furthermore, in order to divide the data into sleep and wake episodes, a smoothing algorithm was applied. For this each sleep period only started when the infant was asleep for at least 10 minutes and ended when s/he was awake for at least 10 minutes. Studies often use different criteria to define the beginning and end of a sleep episode (see Meltzer et al., 2012) – some define the beginning of a sleep episode as soon as there are 5 consecutive 'asleep' minutes, in other studies a longer interval is needed. I decided to use a 10-minutes criteria since it is one of the more common rules (Meltzer et al., 2012). Figure 5.1 illustrates the data and different smoothing algorithm using as example the first recorded night of a week from the same infant at 4, 6, 8, and 10 months. The actual data from the actigraph is shown in green and the smoothing algorithm in red. The top graph displays the zero-minute criteria, the middle one the 5-minutes criteria, and at the bottom the smoothing algorithm with the 10-minutes criteria is shown (as applied in this study). The times out of bed as indicated in the sleep diary are given next to the figures.



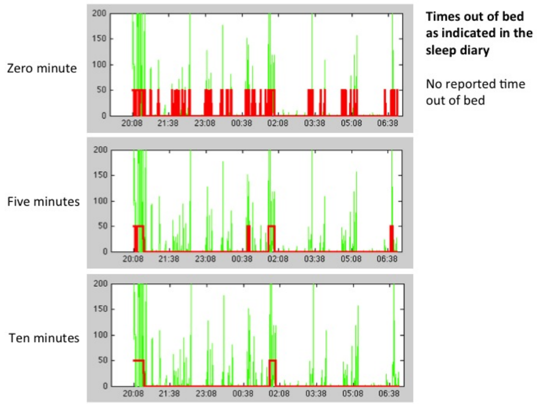
(A) Example from a 4-month-old infant.



(B) Example from a 6-month-old infant.



(C) Example from an 8-month-old infant.



(D) Example from a 10-month-old infant.

FIGURE 5.1: Actigraphy recording from one night and one particular child is shown in those for figures for different time points. For each time point, three versions of a smoothing algorithm (0, 5, and 10 minutes smoothing) were applied and are illustrated in order to show how they impact sleep variables such as number of awakenings.

5.1.3 Sleep Questionnaire

A translated version of the sleep questionnaire employed in this study can be found in the Appendix C. It is a combination of the BISQ described in Chapter 3 and some additional questions that were considered as useful for this study. The BISQ collects data on the infant's average sleep duration during the day and night as well as the number of awakenings and the total time spent awake during the night. Furthermore, there is one question about sleeping arrangements (in a separate room, in parents' bed, etc.), the way how infants fall asleep (being rocked, being fed, alone, etc.), and the sleeping position (belly, back, etc.). Finally, parents are also asked to indicate whether they consider their infant's sleep as a problem.

The additional questions included in the questionnaire aimed to provide more information on parental behaviour around bedtime. We asked whether infants are usually put to bed awake or already asleep, whether parents had the habit of taking their child into their own bed during the night when he/she wakes up, and whether they wait in the room for their infant to fall asleep. Furthermore, parents were asked to describe in a few words their evening ritual if there was one (e.g., bath, feeding, nappy change, singing). Finally, six questions about the parent experiences and sleep were included such as 'Do you experience a lack of sleep, which impacts your daily activities?'.

5.2 Descriptive statistics of the sleep measures

In this section, I will define and describe the extracted sleep variables from the sleep questionnaire and the actigraphy data. They will be split into objective measures derived from actigraphy (section 5.2.1) and subjective measures from the sleep questionnaire (section 5.2.2). Sleep data from two 4-month-olds are missing because of equipment failure, from one 8-month-old because of illness, and from three 10-month-olds because of illness (1), equipment failure (1), and because the family had moved away (1). I excluded abnormal nights such as those where parents reported that the actiwatch had fallen off.

5.2.1 Actigraphy variables

Meltzer et al. (2012) summarised comprehensively how actigraphy data has been reported in pediatric research and pointed out the considerable lack of consistency in which variables have been investigated and how they were calculated. For instance, when reporting 'Bedtime', some papers utilise the times that parents indicate in the sleep diaries while others take only into account the times when infants fall asleep coded by the actiwatches. Meltzer et al. (2012) therefore suggested definitions for variables that should be used in actigraphy research to enable comparison between studies. I applied those definitions in order to define and compute the sleep variables in this study and will shortly refer to each one separately. Since actigraphs were only employed by parents during the night, all objective sleep measures in this study report night sleep variables.

The distributions for the number of nights per age group are presented in Figure 5.2. On average 6.57 nights were recorded per infant and time.

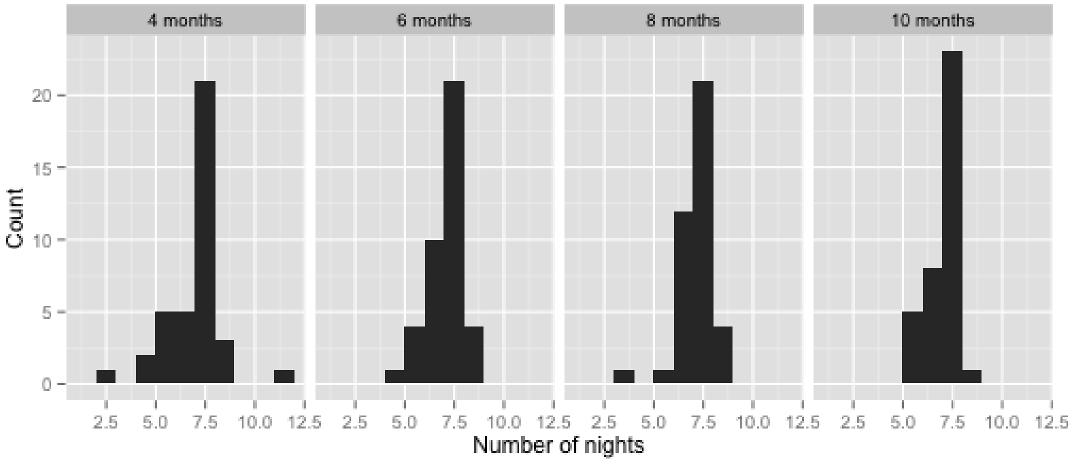


FIGURE 5.2: Distribution of the number of nights assessed per infant and included in the analyses per point in time.

5.2.1.1 Night sleep duration

There are two common variables that relate to sleep duration, which can be assessed using actigraphy.

Sleep period The sleep period is defined as the duration between sleep onset and sleep offset in hours. Sleep onset is at the beginning of the first episode of sleep (that is longer than 10 minutes) whereas sleep offset is the at the end of the last sleep episode of the particular night. A repeated measures ANOVA showed that our infants' sleep periods only marginally changed over developmental time, $F(3, 149) = 2.40$, $p = .071$. A post-hoc test with Bonferroni correction indicated that they only marginally differed between 4 and 8 months (see Figure 5.3 for means and distributions).

Total sleep time The total sleep time is reported in hours and describes the duration of sleep within the sleep period. For its calculation the sleep period is simply subtracted from the total time spend awake. Infants' total sleep time significantly changed with age

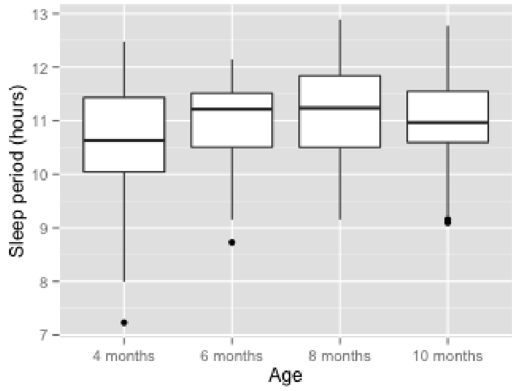


FIGURE 5.3: Sleep period over developmental time.

as calculated by a repeated measures ANOVA, $F(3, 149) = 17.47$, $p < .001$. Post hoc tests with Bonferroni correction revealed that there were significant differences between the infants at 4 months and when they were older (see Figure 5.4).

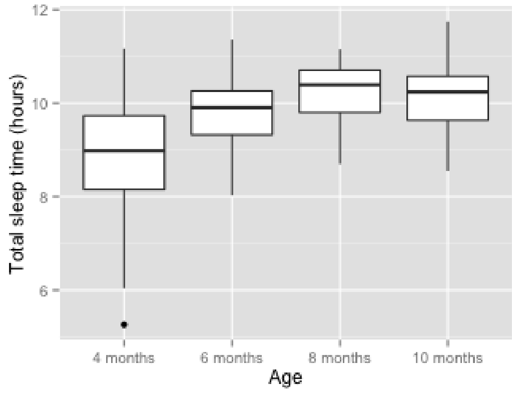


FIGURE 5.4: Total sleep time over developmental time.

5.2.1.2 Night sleep fragmentation

Three variables describe the fragmentation of the night sleep.

Wake after sleep onset The variable 'Wake after sleep onset' is defined as the number of minutes scored as awake during the sleep period and is reported in minutes. A repeated measures ANOVA showed a significant main effect of age, $F(3, 149) = 21.98$, $p < .001$. Post-hoc comparisons using the Bonferroni correction indicated that the means for 'wake after sleep onset' differed between 4 months and the older age groups as well as between

6 and 10 months, with infants waking up less as they get older (means and distributions are illustrated in Figure 5.5)

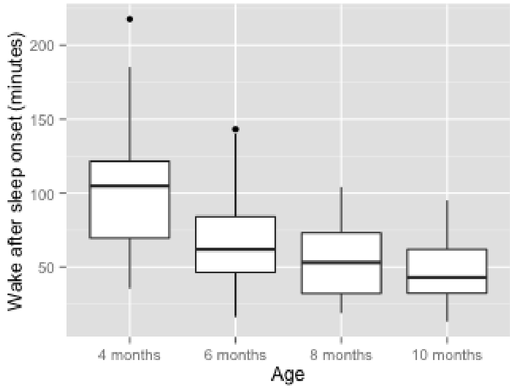


FIGURE 5.5: Wake after sleep onset over developmental time.

Night waking frequency The variable night waking frequency represents the number of night wakings coded with the actigraphy data. In our study infants night waking frequency significantly differed between ages, $F(3, 149) = 19.63$, $p < .001$ (repeated measures ANOVA) and post-hoc t-test with Bonferroni correction showed that there were significant differences between 4 months and older infants and a marginally significant difference between night waking at 6 and at 10 months. Infants woke up less often as they got older (see Figure 5.6).

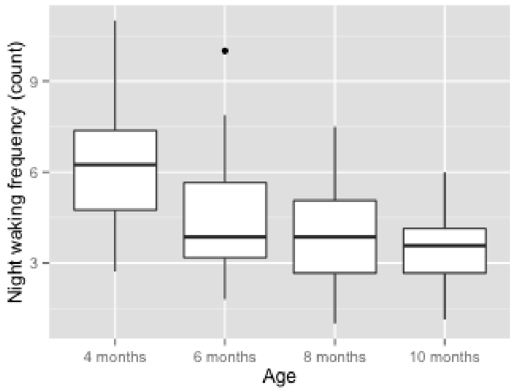


FIGURE 5.6: Night waking frequency over developmental time.

Sleep efficiency In the literature, sleep efficiency is usually calculated in one of two ways. Either it is the proportion of time that infants are asleep within the sleep period or it is the proportion of total sleep time as a function of average time in bed. In this study, we used the first definition: (total sleep time / sleep period) x 100. A repeated measures ANOVA showed a main effect of age, $F(3, 149) = 29.09$, $p < .001$, and Bonferroni corrected post-hoc tests revealed that infants' sleep efficiency significantly increased after 4 months as well as between 6 and 10 months (see Figure 5.7).

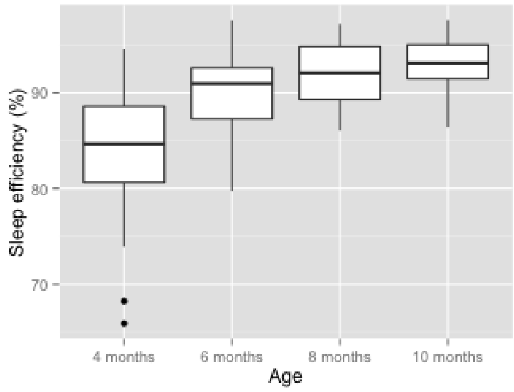


FIGURE 5.7: Sleep efficiency over developmental time.

5.2.1.3 Additional variables

Activity during sleep We furthermore calculated the average activity during sleep time (within total sleep time) as captured with the actiwatch. A repeated measures ANOVA indicated that infants activity differed significantly between ages, $F(3, 149) = 11.05$, $p < .001$, and again post-hoc tests showed that there was a significant reduction of activity between 4 months and older age groups (see Figure 5.8).

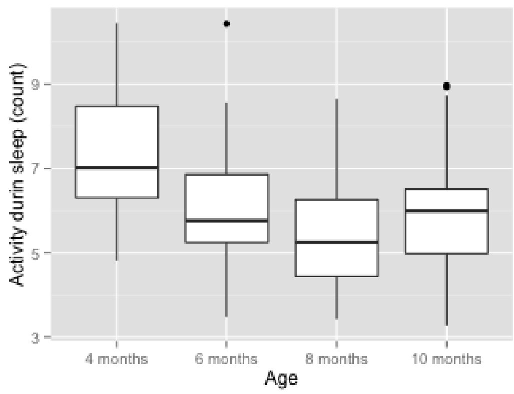


FIGURE 5.8: Activity during sleep over developmental time.

5.2.2 Reported variables from the sleep questionnaire

Sleep characteristics that were reported by the parents in the sleep questionnaire corresponded partly to characteristics that were derived from the actigraphy data. In this study, I used the actigraphy measures by default and only took into account the parent-report measures if there was no overlap. For instance, I used the questionnaire outcome to analyse day sleep because the actiwatches had not been employed during day time. However, in this section, all questionnaire outcomes are explored to check how similar findings from both sources are. Four sleep variables were extracted from the sleep diary using the bedtimes as indicated by the parent, and five sleep variables were assessed using the sleep questionnaire.

5.2.2.1 Sleep duration

Average time in bed during the night (sleep diary) The average time in bed is defined as the time between when the infant was put to bed in the evening and taken out of bed in the morning as indicated in the sleep diaries. A repeated measures ANOVA revealed that there were marginally significant differences between the age groups, $F(3, 149) = 2.40$, $p = .070$. Average times in bed were only marginally significantly different between 4 and 8 months (see Figure 5.9).

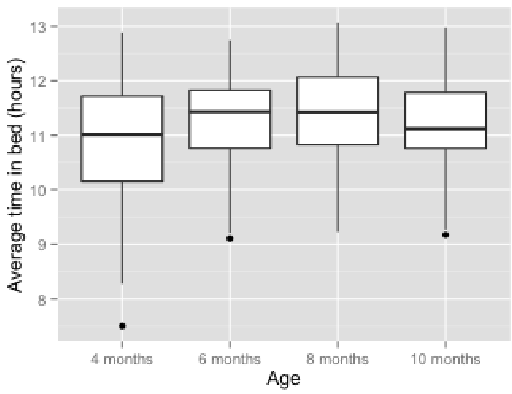


Figure 5.9: Average time in bed as reported in the sleep diaries over developmental time.

Night time sleep (questionnaire) Parents reported in the sleep questionnaire the average night sleep times of their infants. A repeated measures ANOVA indicated that infants' night sleep duration changed with age, $F(3, 149) = 3.47$, $p = .018$, and post-hoc tests with Bonferroni correction revealed that sleep duration differed significantly between 4 and 8 as well as between 4 and 10 months (see Figure 5.10).

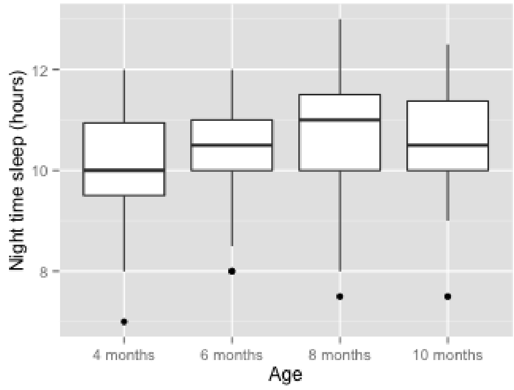


FIGURE 5.10: Night time sleep as reported in the sleep questionnaire over developmental time.

Day time sleep (questionnaire) In the questionnaire parents were also asked to write down the average time their infant usually spent asleep during the day. There was a significant difference between ages as shown by a repeated measures ANOVA, $F(3, 145) = 13.00$, $p < .001$. Post-hoc t-tests with Bonferroni correction indicated that infants slept longer at 4 months than later on (see Figure 5.11).

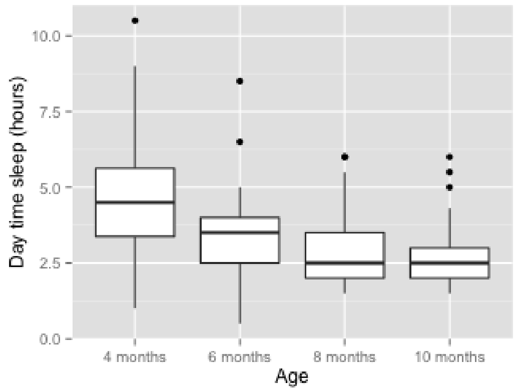
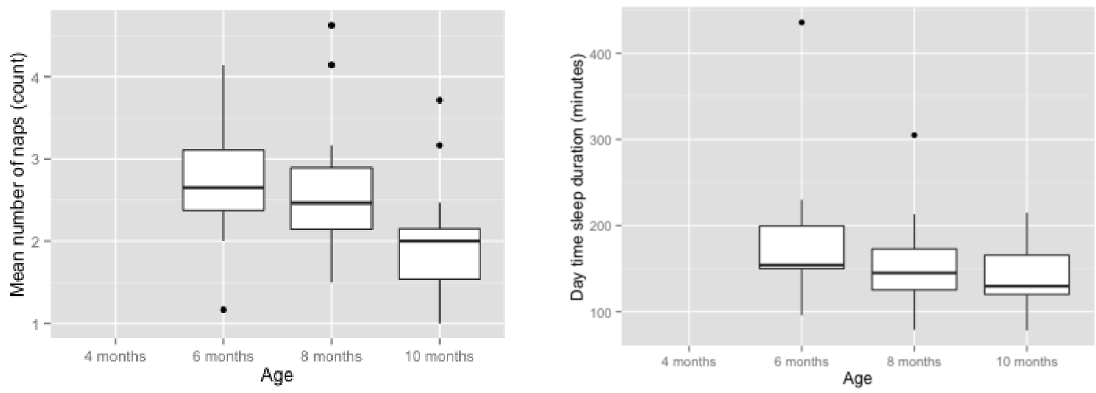


FIGURE 5.11: Day time sleep as reported in the sleep questionnaire over developmental time.

Number of naps (sleep diary) The number of naps was only collected with the sleep diaries at 8 and 10 months and for 11 of the 6-month-old infants. There was a significant change over time, $F(2, 66) = 8, 95$, $p < .001$. As presented in Figure 5.12a unsurprisingly the number of naps decreased over developmental time.

Day time sleep (sleep diary) The mean day sleep duration per infant and time point was calculated using the nap times indicated in the sleep diary (the number of naps were only assessed at age 8 and 10 and for some 6-month-olds). The mean day time sleep duration changed marginally over time, $F(2, 66) = 2.89$, $p = .062$, getting slightly shorter with age (see Figure 5.12b).



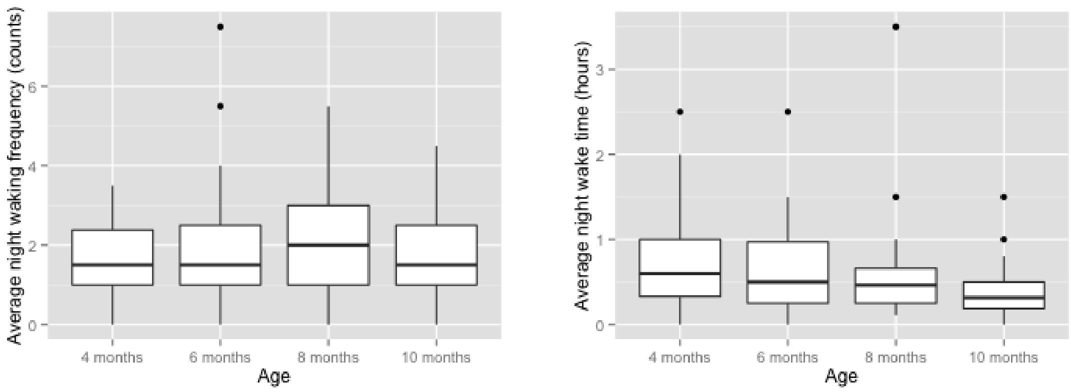
(A) Number of naps over developmental time. (B) Mean nap duration over developmental time.

Figure 5.12: Day time sleep assessed with sleep diaries at 6, 8, and 10 months.

5.2.2.2 Sleep fragmentation

Number of night awakenings (questionnaire) Parents reported in the questionnaire an average number of awakenings for their child at each age. The number of night wakings did not change with age (see Figure 5.13a). This is very surprising given the feeding changes. Potentially, parents only reported the times when their infant got up to get fed at 4 months. Another possible explanation is that parents did not witness the awakenings of their child.

Time awake during the night (questionnaire) Parents indicated in the sleep questionnaire the average time that their infant was sleep during the night. This changed significantly over time, $F(2, 142) = 4.05$, $p = .008$. Post-hoc tests revealed that 10-month-old infants were significantly less awake during the night as reported by the parents than 4 -month-old infants (see Figure 5.13b).



(A) Night waking frequency as reported by the parents over developmental time.

(B) Time awake during the night as reported by the parents over developmental time.

FIGURE 5.13: Night sleep fragmentation assessed by sleep questionnaires at 4, 6, 8, and 10 months.

5.2.2.3 Additional variables

Regularity of sleep onset (sleep diary) Additionally to the variables that have been reported in previous studies, I also investigated the regularity of bed time. For this, the standard deviation of all times from each infant when she/he was put to bed as indicated in the sleep diary was calculated. Although there was great variability between individuals (see Figure 5.14), there were no differences between the age groups as indicated by a repeated measures ANOVA, $F(3, 149) = 0.18$, $p = .908$.

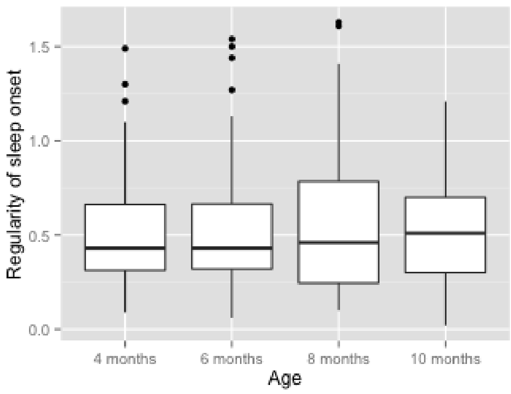


FIGURE 5.14: Activity during sleep over developmental time.

Sleep onset latency (questionnaire) The average time that infants needed to fall asleep reported by the parents did not change with age (see Figure 5.15).

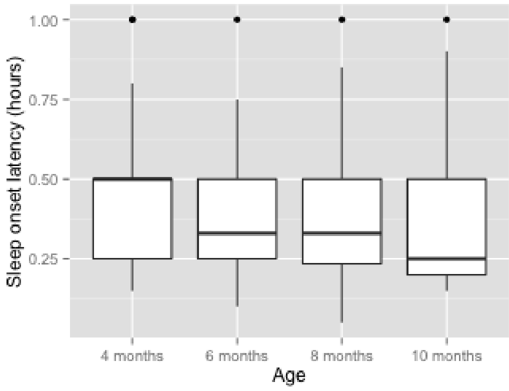


FIGURE 5.15: Sleep onset latency as reported by the parents over developmental time.

5.3 Associations between sleep variables

In order to narrow down the number of sleep variables for further analyses, I carried out a series of correlational analyses with the presented sleep variables. Furthermore, I will explain the criteria of choosing the ones that will also be relevant in the remainder of this thesis.

5.3.1 Correlations between the actigraphy measures

Regarding the variables on sleep duration, there was a very high correlation between total sleep time and sleep period, $r = .82$, $p < .001$ (when tested for each age separately, r ranged between .74 and .93). I choose to continue further analyses with total sleep time since it does take into account only the actual sleep time, which I considered as being the most important variable when describing sleep duration. Furthermore it is the variable that is more often used in the literature.

With respect to sleep fragmentation, the variables 'night waking frequency', 'wake after sleep onset, and 'sleep efficiency' were also strongly correlated with each other, night waking frequency and wake after sleep onset: $r = .89$, $p < .001$ (range of r for each age group separately between .79 and .87), wake after sleep onset and sleep efficiency: $r = -.97$, $p < .001$ (range of r for each age group separately between -.93 and -.99), night waking frequency and sleep efficiency: $r = -.86$, $p < .001$ (range of r for each age group separately between -.76 and -.86). Since in the literature, people often report wake after sleep onset as well as sleep efficiency, I decided to use both variables in the subsequent analyses although they were highly correlated.

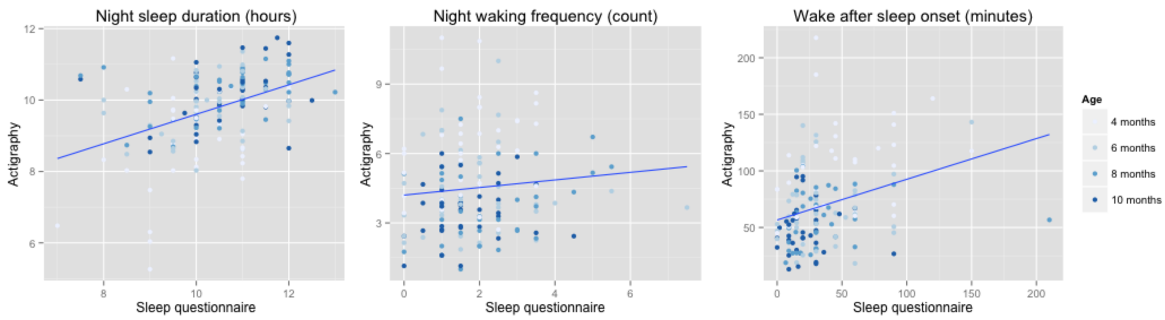
Activity during sleep was only marginally correlated with total sleep time at 4 months, $r = -.30$, $p = .06$. There was a negative association between activity during sleep and sleep efficiency for all age groups. However it was stronger in the younger infants.

Correlations between variables of sleep duration and sleep fragmentation were not significant when investigating each age group separately, e.g., range of r for wake after sleep onset vs. total sleep time between -.31 at 4 months ($p = .06$) and .26 at 10 months ($p = .12$).

5.3.2 Differences between actigraphy and parent report

In order to test whether parents estimation of their infant's sleep duration and sleep fragmentation matched the values assessed by actigraphy, I correlated the complementary variables with each other. Regarding sleep duration, the average night sleep time from the questionnaire and the total sleep time from the actiwatch were highly correlated with each other, $r = .43$, $p < .001$ (Figure 5.16a). Parents overestimated the sleeping time of their infant (mean was 10.39 hours compared to the total sleep time assessed by actigraphy of 9.74 hours), $t(305.77) = 5.25$, $p < .001$. Regarding the sleep fragmentation variables, I first compared the average night waking frequency as indicated in the questionnaire with the night waking frequency from the actigraphy data. Those two variables did not match, $r = .1$, $p = .227$ (Figure 5.16b). However, the average time awake as indicated in the sleep questionnaire and the 'wake after sleep onset' variable from the actigraphy data were again correlated, $r = .31$, $p < .001$. However, as can be seen in Figure 5.16c, parents seriously underestimated this duration: the mean time awake in the questionnaires was 34.87 minutes, while the mean wake after sleep onset calculated with the actigraph data was 68.76 minutes, $t(153.07) = -22.88$, $p < .001$.

In summary, parents were more accurate estimating their infant's sleep duration than estimating sleep fragmentation. This is in accordance with previous findings (Werner et al., 2008). Some infants may call for attention as soon as they wake up while others may rather self-soothe and fall asleep on their own so that parents are not aware of the sleep waking frequency.



(A) Total sleep time assessed by actigraphy and questionnaires.

(B) Night waking frequency assessed by actigraphy and questionnaires.

(C) Wake after sleep onset assessed by actigraphy and questionnaires.

FIGURE 5.16: Correlation between actigraphy and parent-report for different variables of night sleep duration and night sleep fragmentation.

5.3.3 Correlation between sleep questionnaires and sleep diaries for variables describing day sleep

Since, I did not collect actigraphy data during the day, I relied on parent report from the questionnaires and sleep diaries for daytime variables. In order to check whether average estimations of day time sleep from the questionnaires and reports of nap times agreed, I calculated the correlation for the 8- and 10-month-old infants. As presented in figure 5.17, there was a high accordance, $r = .36$, $p < .001$. In further analyses, I therefore decided to use the day sleep duration reported in the questionnaires.

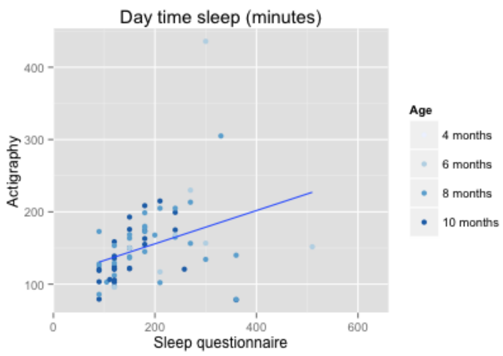


FIGURE 5.17: Correlation between the average day sleep duration reported in the questionnaire and the mean day sleep duration calculated from the napping times in the sleep diary.

5.3.4 Individual stability

Total sleep time (actigraphy) Total sleep time between 4 and 6 months was not significantly correlated, $r = .32$, $p = .15$. However, there was a positive correlation between 6 and 8, $r = .46$, $p = .01$, as well as between 8 and 10 months, $r = .61$, $p < .001$ (all correlations adjusted for multiple tests). Also the correlation between 6 and 10 months was significant, $r = .42$, $p = .04$. This suggests that very young infants have higher intra-individual variance, which decreases as they get older.

Wake after sleep onset (actigraphy) Wake after sleep onset revealed the opposite effect than night sleep duration regarding inter-individual stability. Correlations adjusted for multiple tests were significant and positive between 4 and 6 months, $r = .57$, $p < .01$, but only marginally significant between 6 and 8, $r = .36$, $p = .10$, and 8 and 10 months, $r = .40$, $p = .08$. Furthermore, there was no long-term stability between 6 and 10 months.

Sleep efficiency (actigraphy) Unsurprisingly, sleep efficiency showed similar effects as wake after sleep onset. There was a significant correlation in young children betwee:n 4 and 6 months, $r = .52$, $p < .01$, but not in the older age groups, 6 vs. 8 months: $r = .37$, $p = .10$, 8 vs. 10 months: $r = .37$, $p = .11$.

Day sleep duration (questionnaire) Reported day sleep durations were stable between all adjacent age groups and marginally significant over longer periods of time: 4 vs. 6, $r = .82$, $p < .01$, 6 vs. 8: $r = .52$, $p < .01$, 8 vs. 10: $r = .90$, $p < .01$.

Regularity of sleep onset (sleep diary) The regularity of bedtime was not correlated between 4 and 6 months, $r = .24$, $p = .43$, and only marginally between 6 and 8 months, $r = .37$, $p < .10$. However, there was a strong relation between bedtimes at 8 and at 10 months, $r = .65$, $p < .01$. This suggests that families develop a greater rhythm in their infant's sleep over time, which stays relatively stable after month 8.

Sleep onset latency (questionnaire) The sleep onset latency as reported by the parents was only stable between 6 and 8 months, $r = .53$, $p < .01$.

5.4 Sex differences

There were no significant differences between boys and girls regarding night sleep duration and fragmentation.

5.5 Summary

Sleep duration and sleep fragmentation assessed by actigraphy differed significantly between 4 months and older ages: infants slept shorter during the night as well as woke up more often when they were younger. One possible explanation could lie in their different feeding needs at different ages. Infants also slept longer during the day at 4 months, which suggests that they compensated for their poorer sleep quality and shorter night sleep duration and that the total sleep time was more distributed over a 24-hours-cycle. The regularity of bedtime and the sleep onset latency, however, did not change over developmental time, but there was a high inter-individual variability in both variables.

The individual stability was higher in older ages for sleep duration and higher in younger ages for sleep fragmentation. Sleep fragmentation in young infants is more influenced by feeding needs while in older infants this can be related to a variety of other reasons that are not consistent over time, e.g., a burst of growth, teething etc. Generally, parents were better in estimating their infant's sleep duration compared to their infant's sleep fragmentation.

I decided to further explore the actigraphy variables total sleep time, wake after sleep onset, and sleep efficiency in analyses relating sleep and cognitive development. Those were highly correlated with other excluded variables (for instance total sleep time is related to sleep period) and I wanted to focus on a smaller number of measures. Furthermore, I planned to integrate the day sleep duration reported in the questionnaires in subsequent analyses. Finally, I planned to examine sleep onset latency (questionnaires), sleep onset regularity (sleep diaries), and activity during sleep (actigraphy) in the analyses.

Chapter 6

Sleep in the Social Context

In this chapter I will first report characteristics of the families involved in the study and how they correlated with the sleep variables. Then I will summarise the sleeping arrangements and behaviours around bedtime that families applied and how they were associated to infants' sleep variables. Finally, I will briefly summarise the emotional experience of the parents during bedtime as well as their perceived sleep quality. Data on the socio-economic background was collected using a questionnaire that parents filled in at the beginning of the study (see Appendix D) and information on the bedtime environment was collected through the sleep questionnaire (see Appendix B).

6.1 Socio-economic background

Adult studies on the link between socio-economic status (SES) and sleep variables have yielded inconsistent findings. For instance one study with more than 1000 participants showed that although SES is related to mental and physical health, there is no direct association with sleep quality (P. J. Moore, Adler, Williams, & Jackson, 2002). Nevertheless, sleep was found to mediate the effects of income on mental and physical health. However, another study reported more sleep complaints in a low SES sample (Grandner et al., 2010). With respect to children, Buckhalt et al. (2007) found longer sleep durations in European American children compared to African American children who scored somewhat lower on SES. Furthermore, in their study sleep only served as a mediator for cognitive performance in the high SES group, but not in the low SES group. As far as I know, there are no studies comparing infant sleep from different SES backgrounds.

6.1.1 Descriptive statistics

Educational background of the parents In the first questionnaire that parents received they were asked to indicate their highest educational degree (from both father and mother) as well as the number of siblings of the participating infant. Nine mothers had a university degree, 21 a college degree (German Fachhochschule), 9 one from secondary school (German Realschule), and one had gone to main school (German Hauptschule). Regarding the fathers, there was a similar distribution: 9 had a certificate from university, 20 from college, 4 from secondary school, and 7 from main school. Since the educational status of fathers and mothers was positively correlated, $r = .36$, $p = .02$, I calculated for further analyses an overall 'education' variable by computing the mean from both measures.

Siblings Fifteen participating infants were first-born, 21 had one older sibling, and 4 had two siblings.

6.1.2 Relation between family background and sleep

In our sample, neither SES nor the number of siblings were related to the sleep variables (tested using correlations that were adjusted for multiple tests).

6.2 The bedtime environment

Parents' behaviour around bedtime differs considerably: some parents prefer to leave their child alone in a room while he/she is still awake while others rock their infant to sleep. In general, this increased parental involvement during bedtime was shown to relate to more night awakenings and an increased time awake during the night (Sadeh et al., 2010, for review). For instance, Adair et al. (1991) found that when parents stayed in the room and waited until their 9-month-old falls asleep, the infant subsequently woke up significantly more often. Sadeh et al. (2010) assumed that infants do not learn to self-sooth and regulate themselves when parents are much involved at bedtime. Consequently, they expect to be rocked, hold, or fed to sleep not only during sleep onset but also when they wake up during the night. However, Sadeh et al. (2010) also stated that there is a lack of longitudinal studies investigating how those behaviours evolve. Maybe parents simply adapt to their infant's sleep problems by providing more presence during bedtime.

Nevertheless, having a bedtime routine was found to be crucial. For example, in a randomised controlled trial Mindell, Telofski, Wiegand, and Kurtz (2009) showed that infant sleep problems improved after the implementation of an evening ritual that consisted of a bath and a baby massage. However, the participating infants in this study all had small to severe sleep problems, so whether an evening ritual makes any difference in the habitual sleep of infants without a problem remains unclear.

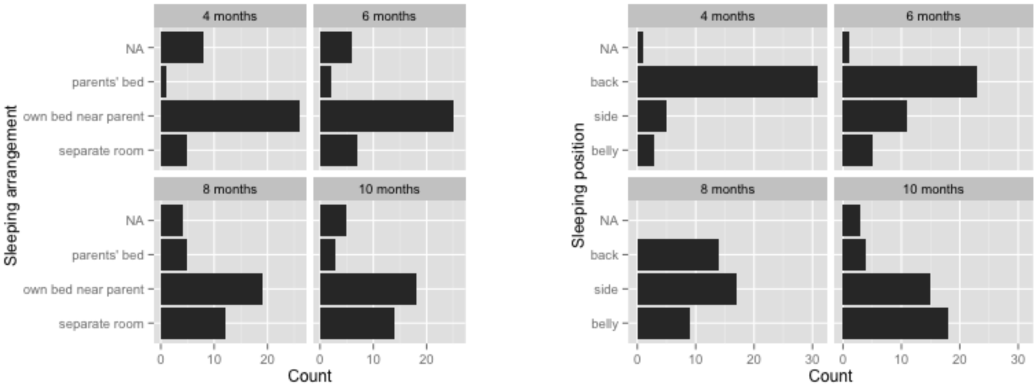
6.2.1 Descriptive statistics

Sleeping arrangements Parents reported regularly via the questionnaire where and in what position their infant slept. At 4 months, most of the infants slept in their own bed in their parents' bedroom, whereas this number decreased over developmental time. Instead the number of infants who slept in an separate room increased over developmental time. A chi-square test was performed and revealed a marginally significant relationship between age and sleeping arrangement, $\chi^2(6) = 10.86$, $p = .093$, suggesting that infants were more likely to sleep in a separate room as they got older (see Figure 6.1a).

Regarding the sleeping position, most infants slept on their back at 4 months but, with time, more started to sleep on their belly or their side (see Figure 6.1b). A chi-square test showed a significant change over time, $\chi^2(6) = 45.39$, $p < .001$.

Parent behaviour Most parents in this study did not consider their infant's sleep to be a problem (see Figure 6.2a) and there was no change over time regarding their perception, $\chi^2(6) = 6.71$, $p = .349$.

With respect to the behaviour at bedtime, three questions were asked in the sleep questionnaire (see in Figures 6.2b, 6.2c, and 6.2d). The majority of infants was put to bed awake over all ages, $\chi^2(3) = 3.09$, $p = .377$ (Figure 6.2b). However, the number of



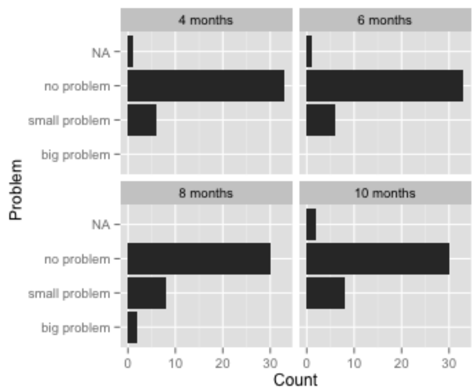
(A) Frequency distribution of three sleeping arrangements at 4, 6, 8, and 10 months.

(B) Frequency distribution of three sleeping positions at 4, 6, 8, and 10 months.

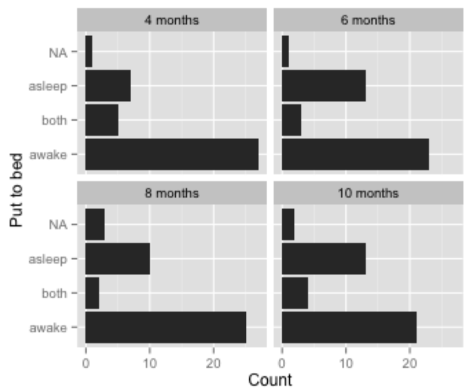
Figure 6.1: Frequencies of sleeping arrangements and positions from infants at 4, 6, 8, and 10 months as parents reported in questionnaires.

parents who waited in the room until their infant fell sleep was approximately equal to the number of parents who left while the infant was still awake (Figure 6.2c). From the subgroup of waiting parents, again approximately half of them had physical contact with their child while he/she fell asleep, i.e., they fed, held them in their arms etc. (Figure 6.2d).

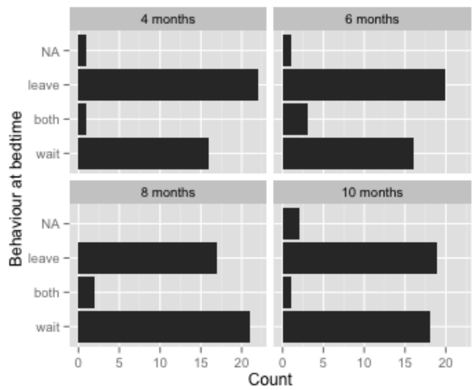
Moreover, parents were asked to describe their evening ritual, if there was one. I grouped the answers into 5 different groups. If parents had indicated in a previous question that they left the room before their child fell asleep, I coded their evening ritual into 'not a specific one', 'small ritual', and 'long ritual'. The 'not specific' group contained parents who had no particular routine. A 'small routine' was coded if parents indicated that they had a routine, which consisted of behaviours that were not specific to the evening, i.e., nappy change, feeding, etc. A 'long ritual' consisted of elements in the routine that only happened in the evening such as taking a bath, listening to the same melody every night etc. Parents who stayed in the room until their child was asleep were coded into two groups. The first group had no specific routine before bedtime or they applied behaviours that also happened during the day. The second group had a special evening routine (bath etc). It is unfortunately not possible from the responses in the questionnaire to differentiate a positive versus chaotic lack of routine. Frequency distributions for all ages are presented in Figure 6.3.



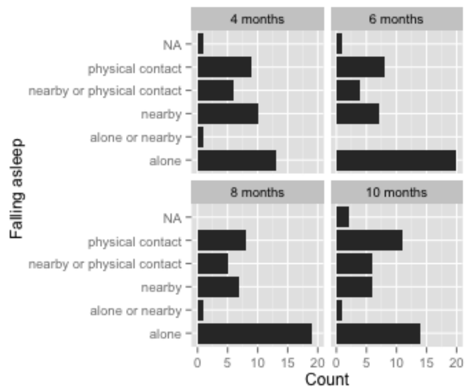
(A) Do you consider your infant's sleep as a problem? Answers across ages.



(B) Do you put your baby into bed awake or asleep? Answers across ages.



(C) Do you wait until your infant is asleep or do you leave the room? Answers across ages.



(D) How does your baby fall asleep? Answers across ages.

Figure 6.2: Frequencies of answers for questions on parental behaviour at bedtime at 4, 6, 8, and 10 months.

6.2.2 Relation between sleeping arrangements / parental behaviour and sleep

In order to test whether the sleeping arrangement and the behaviour of the parents had an impact on any of the sleep variables, I conducted a series of ANOVAs.

Total night sleep time, wake after sleep onset, and night sleep efficiency were unrelated to the sleeping arrangement. There is a vivid debate and much controversy in the literature about whether infants should co-sleep or be in a solitary room. For several decades bed- or room-sharing was discouraged because it was believed that this would not help their children to become independent and confident. During the last decades, Western mothers increasingly adapted to breast-feeding as opposed to formula, which also changed sleeping arrangements: since breast-feeding comes along with more awakenings families

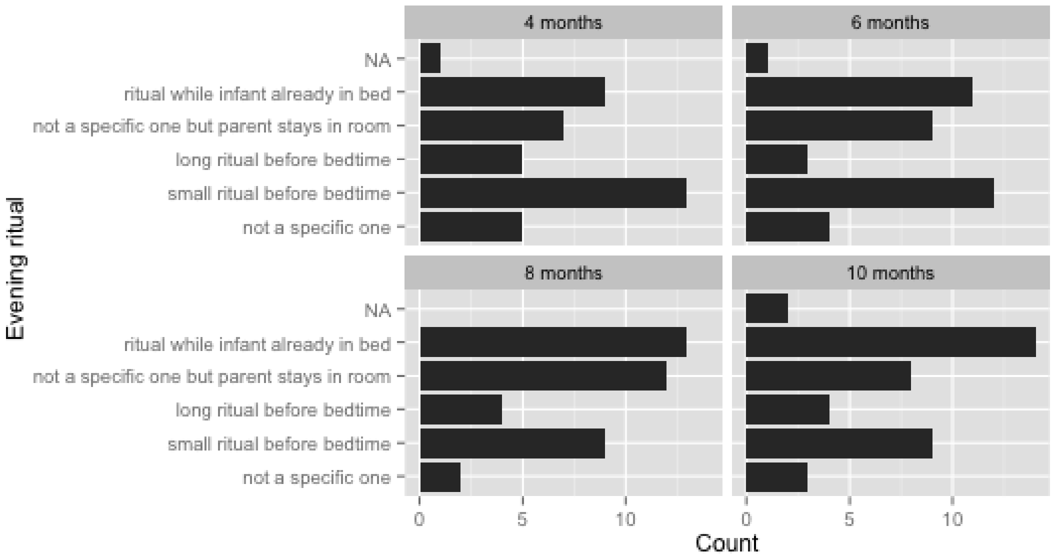


FIGURE 6.3: Coding of the evening ritual at 4, 6, 8, and 10 months.

more often co-slept or shared the same room. A broad body of literature has investigated sleeping patterns that are associated with those different sleeping arrangements. It came to the conclusion that co-sleeping increased the number of awakenings, but not the total time awake during the night (Mao, Burnham, Goodlin-Jones, Gaylor, & Anders, 2004). Furthermore, co-sleeping infants and mothers spent less time in deep sleep compared to infants and mothers sleeping in separate rooms (Mosko, Richard, & McKenna, 1997b; Mosko et al., 1997a). Sudden infant death syndrome was associated most to infants sleeping in a separate room and to co-sleeping infants whose parents smoked or had consumed alcohol (Blair et al., 1999; Carpenter et al., 2004). Room-sharing but not bed-sharing was found to be most advantageous: less risk for sudden infant death syndrome and increased parental availability compared to the separate room arrangement but less sleep disturbance than when co-sleeping (McKenna & McDade, 2005). It is probable that no correlation emerged between sleep variables and sleeping arrangements in this study because most parents used – at least in the first months – the room-sharing option. The infants' sleeping position did not relate to any of the sleep variables.

In the current study, most parents did not consider their infant's sleep to be a problem. Nevertheless, I computed correlations in order to check whether their report related to their infant's sleep pattern. However, none of the relations was significant. Only at 8 months, infants went to bed more regularly when their parents considered their sleep as a problem, $r = -.52$, $p = .01$. Maybe, more rigid parents were stricter about when their infant should sleep, and even if this routine was broken rarely, they considered it problematic.

Parental behaviour at bedtime was generally not related to sleep variables in this study. The former mentioned study on bedtime routines only included infants with a sleep problem. Teti, Kim, Mayer, and Countermine (2010) suggested in another study, that emotional availability around bedtime was related to decreased night awakenings and may be more important than specific behaviours. It is possible that different infants have different needs: either a more structured routine and clear clues if they have sleep problems or simply just emotional clues if they easily fall asleep on their own.

6.3 Parent sleep

6.3.1 Descriptive statistics

Regarding the parents' emotional experiences around bedtime (mostly mothers since only one caregiver filled out the questionnaire), most of the parents enjoyed taking their infant to bed in the evening (4 months: 90%, 6 months: 92%, 8 months: 95%, 10 months: 97%). Furthermore, most of them also liked watching their sleeping infant (4 months: 87%, 6 months: 92%, 8 months: 95%, 10 months: 92%).

With respect to the parents' own sleep, only a minority felt sleep deprived so that their daily life was impaired (4 months: 10%, 6 months: 8%, 8 months: 8%, 10 months: 0%). Nevertheless, the number of parents who regularly felt sleepy was greater (4 months: 24%, 6 months: 17%, 8 months: 13%, 10 months: 8%). Only 3% of the parents indicated that they had already experienced a permanent lack of sleep before their infant's birth. Very few parents indicated that their lack of sleep also impaired their marital quality (4 months: 8%, 6 months: 5%, 8 months: 8%, 10 months: 0%). Interestingly, parent sleep problems were not correlated with infant sleep fragmentation, e.g., for number of awakenings $p = .60$. However, there was a marginally significant correlation between parental sleep problems and infant sleep duration, for total sleep time: $r = -0.14$, $p = .08$.

6.4 Summary

The participating families had a caucasian background and parents with high, middle, and low educational status were represented. The majority of parents did not consider their infant's sleep to be a problem and did not experience a lack of sleep on their own that impaired their daily life. Most infants slept at 4 months in their own bed in the parents' bedroom, but moved to their own room over the course of the study. Regarding the parental involvement at bedtime, about half of the parents stayed with their infant until he/she was asleep whereas the other half left while their infant was still awake, expecting them to self-sooth into sleep. Most families had a bedtime routine. Habitual sleep was neither related to the family background nor to parental behaviour at bedtime or sleeping arrangements. This might be due to the fact that most infants had no sleep problems and did not co-sleep.

Chapter 7

Sleep Patterns and the Ages & Stages Questionnaire

In this chapter, I will first report the scores obtained from the Ages & Stages questionnaire. I will then outline the associations between those outcomes and the sleep variables.

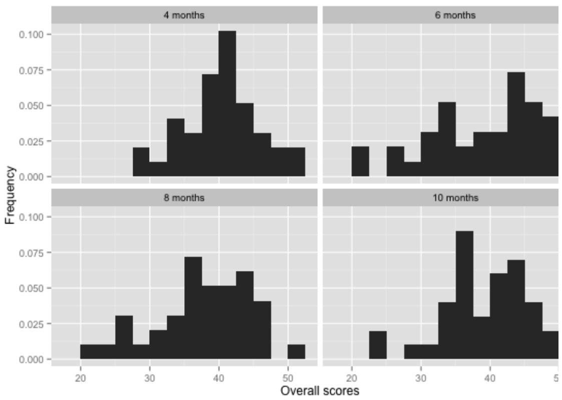
The Ages & Stages questionnaire is a screening tool for the first years of live, which gives scores for different developmental domains (see Squires et al., 2009). The English questionnaire for 4, 6, 8, and 10 months as well as a corresponding translation in German can be found in Appendix E. The five sub-scales consist of 6 questions each and cover gross and fine motor development, communication, problem solving, as well as personal / social development. An example question for the sub-scale 'communication' at 6, 8, and 10 months is: "Does your baby make sounds such as 'ga', 'da', 'ka', or 'ba'?" (one question on communication in the version for 6-months-olds). Another example question from the 'gross motor' sub-scale at 8 and 10 months is: "When sitting on the floor, does your baby sit up straight for several minutes without using her hands for support?". Answers can be "yes", "sometimes", or "no". It is the most used parent-completed questionnaire for screening development (Hornman, Kerstjens, de Winter, Bos, & Reijneveld, 2013). Its sensitivity and specificity are good (75% and 81%) and it has modest agreement with the Bayley-III ($r = 0.56$) (Schonhaut et al., 2013). In this study, the versions for 4, 6, 8, and 10 months were used. I just know of one study that employed the Ages & Stages questionnaire in relation with sleep variables. They found that sleep efficiency in infants was positively correlated to problem solving, and a higher proportion of night sleep to communication and problem solving (Gibson et al., 2011).

The questionnaires were coded according to the manuals by rating each answer (no = 0, sometimes = 5, yes = 10) and summing up obtained scores. Furthermore, the questionnaire user guide gives cutoffs for each subscale and age group. Infants were grouped into three categories according to their scoring in each sub-scale: "below the cutoff", "close to the cutoff", and "above the cutoff".

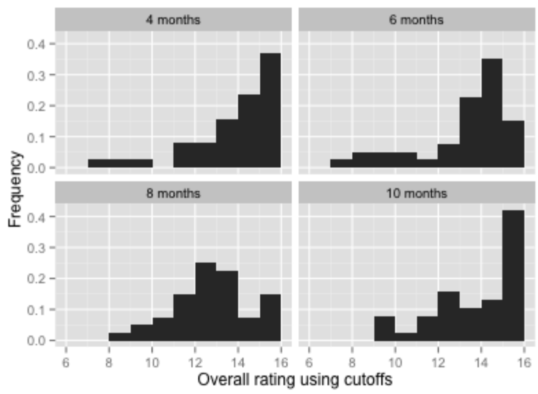
7.1 Descriptive statistics of the Ages & Stages questionnaire

7.1.1 Overall scores

Two overall scores from the Ages & Stages questionnaire were calculated. For the first one – Overall A – the total scores of the sub-scales per child were averaged. Distributions are presented in Figure 7.1a. It represents the general rating of an infant's development compared to his or her peers. For the second score – "Overall B" – infants were grouped according to the cutoff in each sub-scale: "below cutoff" was rated with 1, "close to cutoff" was rated with 2, and "above cutoff" with 3. Those scores were summed per child and age and are presented in Figure 7.1b. Overall B represents how critically different the general development if infants are compared to their peers.



(A) Overall A: distribution of the overall Ages & Stages questionnaire scores for each age group.



(B) Overall B: in the Ages & Stages questionnaire infants below the cutoff were coded with 1, close to the cutoff 2, and above the cutoff 3 for each sub-scale. The figure shows the distributions of the summed ratings per child and age.

FIGURE 7.1: Distribution of the overall scores in the Ages & Stages questionnaire.

Neither score was not significantly correlated with parental education or number of siblings. The Overall A score was not stable over developmental time (r ranging between .15 and .39). But the Overall B score was highly correlated across all ages: 4 vs. 6 months: $r = .53$, $p < .01$, 6 vs. 8 months: $r = .63$, $p < .01$, 8 vs. 10 months: $r = .63$, $p < .01$. Even over a longer period of time, the ratings were still significantly and positively correlated (r ranging from .49 to .58).

7.1.2 Subscales

Means and standard deviations for the subscales and all ages are presented in table 7.1. Scores range from 0 (lowest) to 60 (highest). Also the number of infants in the "below the cutoff" and "close to the cutoff" group are reported in the table for each sub-scale and age.

Table 7.1: Means and standard deviation in brackets for all subscales of the Ages & Stages questionnaire and all ages separately. Numbers of infants below and close to the cutoff are given for each subscale and age.

	4 months	6 months	8 months	10 months
N	38	40	40	38
Communication	54.61 (6.41)	49.00 (8.64)	52.88 (7.24)	46.97 (10.56)
Below, close to cutoff	0, 6	1, 6	0, 4	0, 3
Gross Motor	52.63 (9.50)	31.50 (11.61)	34.50 (15.68)	42.24 (20.42)
Below, close to cutoff	8, 6	7, 5	19, 4	7, 3
Fine Motor	45.39 (12.86)	39.62 (10.65)	50.00 (12.61)	53.95 (10.08)
Below, close to cutoff	8, 9	6, 4	9, 6	4, 6
Problem Solving	48.68 (12.23)	46.50 (11.50)	52.88 (8.61)	50.53 (7.60)
Below, close to cutoff	5, 6	1, 6	3, 11	1, 7
Personal Social	48.68 (11.66)	39.38 (11.22)	47.00 (10.05)	42.11 (10.76)
Below, close to cutoff	4, 9	7, 4	7, 8	4, 7

Neither the normal ratings of the sub-scales nor the cutoff ratings were related to parental education or number of siblings. There was individual stability between 6 and 8 months in the 'Gross Motor' scale with the normal rating, paired correlation adjusted for multiple tests: $r = .45$, $p = .03$. However, the cutoff rating was stable on the 'Communication' scale between 8 and 10 months, $r = .46$, $p = .02$, on the 'Problem Solving' scale between 8 and 10 months, $r = .59$, $p < .01$, in the 'Personal / Social' scale between 4 and 6 months, $r = .51$, $p = .01$, and in the 'Gross Motor' scale between 6 and 8, $r = .44$, $p = .02$, as well as between 8 and 10 months, $r = .52$, $p < .01$.

7.2 Concurrent and longitudinal relation between the Ages & Stages questionnaire and habitual sleep

I explored associations between ratings in the sub-scales and the sleep variables chosen in Chapter 5 (night sleep duration, wake after sleep onset, sleep efficiency, day sleep duration, sleep onset regularity, sleep onset latency).

Regarding the **concurrent association** between sleep and the Ages & Stages questionnaire, I conducted a series of paired correlations. 10-month-old infants who scored below or close to the threshold in the 'gross motor' and 'problem solving' scale slept longer, gross motor: $r = -.57$, $p < .01$, problem solving: $r = -.52$, $p = .03$ (adjusted for multiple tests). I also computed correlations between problem solving / communication and the proportion of night sleep time as in the study of Gibson et al. (2011) but failed to replicate their results.

Furthermore, there were no significant **longitudinal associations** between early sleep variables and later scores on the Ages & Stages Questionnaire.

7.3 Summary

There was individual stability in the overall score of the Ages & Stages questionnaire at all ages as well as in some sub-scales, particularly in older infants. The scores were not related to parental education or whether the infant had an older sibling or not. Regarding sleep, 10-month-olds who scored below the cutoff in problem solving and gross motor score slept longer. There were no longitudinal associations between early sleep and later outcomes in the questionnaire.

Chapter 8

Habitual Sleep and Short-term Memory in Infancy

8.1 Introduction

Infants spend more than half of their first year of life in a sleeping state (Dahl, 2009). Sleep is crucial for behavioural, physiological, and neuro-cognitive development and functioning (Curcio et al., 2006; Banks & Dinges, 2007; Diekelmann et al., 2009). Moreover, certain parts of the brain are more active during sleep than wakefulness (Carskadon & Dement, 2011). Getting sufficient sleep is therefore likely to be crucial, not just for resting the brain and body, but also for optimal short- and long-term development. Although there is now a relatively large body of literature investigating direct sleep effects on specific learning in older children and adults (Diekelmann & Born, 2010; Gómez et al., 2011, for review), our knowledge of the relation between sleep and cognition in infancy remains limited.

There are three ways in which the role of sleep on learning and development might be considered. First, learning followed by sleep may be directly related to specific knowledge consolidation (e.g., Fenn et al., 2003; Gómez et al., 2006). Here, the results of training are tested after a period of sleep in one group and compared with the performance of another trained group being tested after the same period of time but without intervening sleep, e.g., it has been shown that naps foster the learning of statistical regularities in 15-month-olds (Gómez et al., 2006; Hupbach et al., 2009) and in adults (Lau et al., 2011).

The second relation – concurrent effects of sleep on performance – is examined by measuring recent habitual nocturnal sleep variables and relating these to ongoing cognitive abilities (e.g., Weissbluth & Liu, 1983). Third, sleep may be related to general cognitive development as one of the factors that fosters longitudinally optimal neuro-cognitive functioning (e.g., Diekelmann et al., 2009). This is examined by associating sleep characteristics earlier in development with cognitive abilities in the same individuals at a later age. The current study focused on the second and third of these relations: concurrent and longitudinal effects of sleep variables on cognitive development, particularly with respect to short-term memory.

8.1.1 Associations of sleep and memory development in infancy

To our knowledge, very few studies (Ednick et al., 2009; Gómez et al., 2011, for review) have examined the relation between aspects of sleep variables and concurrent or longitudinal measures of cognitive abilities. Studies looking at concurrent associations have examined habitual sleep characteristics, which were usually collected via parent report or actigraphy, and mental development at a single point in time. In one study, sleep characteristics were measured using actigraphy in fifty 10-month-old infants (Scher, 2005). Sleep efficiency – the proportion of time spent asleep during the night – was positively related to mental development scores assessed with the Bayley Scales of Infant Development, whereas sleep fragmentation as well as activity during sleep were negatively related to Bayley scores. In a second study, parents were asked to complete the Brief Infant Sleep Questionnaire (Sadeh, 2004) and report on the amount of time their child normally slept during the night and the day, as well as how often s/he awakened. Imitation abilities were measured and correlated with the sleep data (Lukowski & Milojevich, 2013). Imitation turned out to be better in children with a lower proportion of night sleep and more daytime napping. Furthermore, studies with preschool and school children found better adjustment, better cognitive functioning, and less behavioural problems in those with less fragmented night sleep (Sadeh, Gruber, & Raviv, 2002; Bates, Viken, Alexander, Beyers, & Stockton, 2002). These findings point to a possible link between habitual sleep and cognitive functioning at one point in time.

Some studies also examined the longitudinal effects of sleep on cognitive abilities. Interestingly, one study by Freudigman and Thoman (1993) reported that sleep characteristics of newborns on day one, but not on day two, can be related to their mental development measured on the Bayley Scales at 6 months. However, this relation might be explained by pre-existing maturational differences between infants, which account for variations in coping with the stress at birth and thereby influence both sleep on day one and also explain later mental development. Studies of sleep in preterm infants found that sleep-wake patterns (Anders, Keener, & Kraemer, 1985; Whitney & Thoman, 1993), the amount of total night sleep and the level of activity during night sleep (Gertner et al., 2002), cyclicity during quiet sleep (Borghese et al., 1995), as well as sleep EEG (Beckwith & Parmelee, 1986), were all associated with later mental development scores. Sleep may hence serve as predictor of later cognitive functioning in atypically developing populations. In fullterm children, Bernier et al. (2010) found that a higher proportion of total nocturnal sleep at 12 and 18 months was related to better performances on an executive functioning task at 18 and 26 months. Moreover, Dearing et al. (2001) reported better cognitive and language development in children at 24 and 36 months who had higher circadian sleep regulation at 7 and 19 months. All these findings support the idea that the nature of habitual sleep variables is associated with later cognitive development.

None of the studies discussed above has hitherto examined sleep variables over developmental time in the same infants, and related these both concurrently and longitudinally to memory processes – the focus of the study reported in this chapter.

8.1.2 Spatial indexing as a memory measure

Since infants are obviously unable to verbalise what they remember, I chose a paradigm developed by Richardson and Kirkham (2004), which relies on eye movements to measure memory abilities in infants. It is a spatial indexing task, based on paired associate learning, in which infants are familiarised with two different toys each appearing consecutively on different sides of a computer screen and each being paired with a specific sound. After the familiarisation phase, infants hear only each of the two sounds one after another, without the appearance of the relevant objects. Looking patterns are recorded to ascertain whether infants remember the visual-auditory pairing and, on hearing the sound only, look towards the appropriate location where they expect the object to appear. This task was first used in a study where Richardson and Kirkham (2004) investigated the capacity of adults and 6-month-olds to attach multimodal events to locations and track those locations when they moved. Both age groups succeeded on the task. Kirkham, Richardson, Wu, and Johnson (2012) subsequently employed a modified version of the task successfully with 3- and 10-month-olds. Several problems emerge from both studies, however. First, the authors only reported average overall looking times to each location. As different infants experienced a different number of trials (between one and five trials), scores were weighted differently, and it remains an open question as to whether outcomes would have been the same if only the looking times of the very first trial run had been analysed. Furthermore, trials with short overall looking times were weighted less than trials with longer overall looking times. Examining proportions of looking time instead of total looking time could surmount this problem. Therefore, I used only a first task run with the infants in our study and investigated both looking time and proportions of looking time.

8.1.3 The present experiment

In this experiment, I used the spatial indexing task described in the paragraph to measure memory abilities longitudinally at 4, 6, 8, and 10 months in the same infants. Furthermore, I assessed sleep variables in these infants at the same time points, using actigraphy for one week prior to testing memory. Firstly, I hypothesised that performance on the memory task would improve over time. Secondly, I predicted that memory outcomes would be associated concurrently and longitudinally to certain sleep parameters. More precisely I hypothesised that less sleep fragmentation would relate to better performance on the short term memory task.

8.2 Methods

8.2.1 Participants

Forty healthy 3-month-old infants (21 female) were recruited. Sleep data from two 4-month-olds are missing because of equipment failure, from one 8-month-old because of illness, and from three 10-month-olds because of illness (1), equipment failure (1), and because the family had moved away (1). I excluded abnormal nights such as those where parents reported that the actiwatch had fallen off. The mean number of nights recorded per infant and time point was 6.57. Data from the memory task was collected from 33 4-month-old, 38 6-month-old, and 36 8- and 10-month-old infants. Six 4-month-old infants and 4 6-month-old infants were excluded from the analysis because they looked less than 1500ms during one of the test trials.

8.2.2 Stimuli and coding

8.2.2.1 Memory task

We used the paradigm from Richardson and Kirkham (2004) discussed earlier to examine memory abilities in infants (see Figure 8.1).

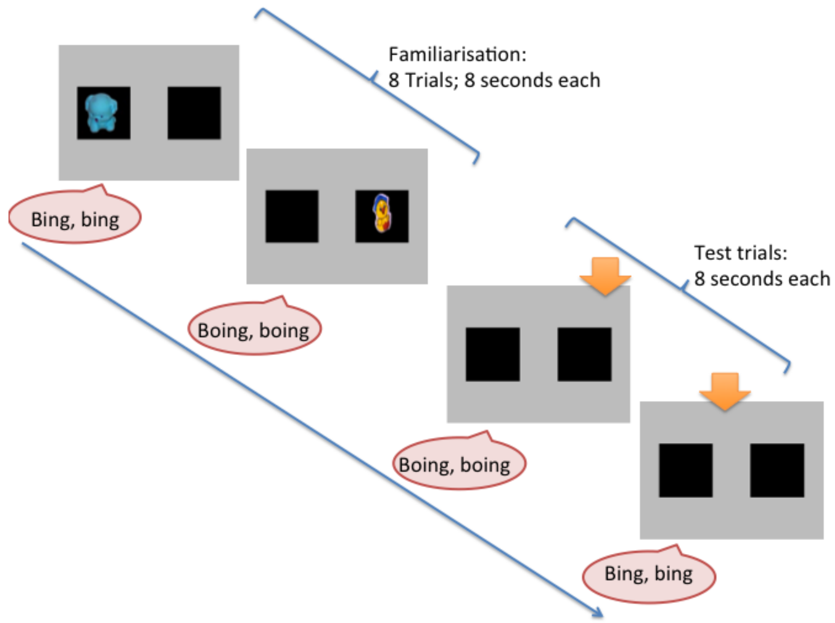


FIGURE 8.1: Illustration of the memory task from Richardson and Kirkham (2004).

During eight familiarisation trials, infants learned to associate the location of one toy (moving slightly within a frame) that was consistently presented on one side of the screen with a simultaneously presented specific sound, and another toy on the other side of the screen with a simultaneously presented different sound. In between each trial, an attention grabber was displayed in the centre of the screen, with the next trial only starting after the infant had fixated this point. The attention grabber was also presented after familiarisation and before the test phase. In the first test trial, infants only heard one of the previously presented sounds for eight seconds but did not see any toy in the two frames. Another attention grabber guaranteed that the infants re-fixated the centre of the screen, after which the other sound was presented during the second test trial. All stimuli were taken from Richardson and Kirkham (2004): the visual toys – a blue dog and a yellow duck – and the auditory stimuli – a 'Boing' sound and a 'Bounce' sound – were randomly matched and two fixed pairings were used in the experiment. For each infant at each age, three parameters were calculated using the looking time data. Henceforth, I will refer to the side of the screen where the toy object associated with a sound should have appeared as the 'correct side', and the other side as the 'incorrect side'. To separate these two regions of interest, the screen was divided as in Richardson and Kirkham (2004). First, the duration of looking time to the correct and incorrect side was captured. Second, the percentage of looking time to the correct side was calculated by dividing the overall looking time to both sides by the total looking time to this side. Third, the direction of the first saccade was coded with 1 when the first saccade went from the centre of the screen towards the correct side, and with 0 when it failed to go from the centre of the screen towards the correct side. Trials in which the saccade did not clearly start in the centre of the screen were handled as missing data. The direction of the first saccade was measured because I wanted to investigate whether infants who look equally long to both sides start searching at the correct side first. All three variables were calculated separately for the first and the second test trial as well as for both test trials together.

8.2.2.2 Sleep data

We used actigraphy and parental report of their infant's sleep to assess sleep during the week prior to each visit. As mentioned in an earlier chapter, parents were asked to fill in a sleep diary for seven consecutive nights in which they recorded each time their baby fell asleep and awakened. Furthermore, they described any events during the night that occurred while the infant was awake, such as 'feeding' and 'nappy change', as well as any events that could influence the infant's sleep (e.g., illness, vaccination). Secondly, actigraphy data were recorded for seven consecutive nights. Using as boundaries the times at which the infant went to bed and got up as indicated in the sleep diaries, I processed the actiwatch data within this time frame with an algorithm from the Respironics Software for this device, which coded each 30-seconds epoch as 'awake' or 'asleep'. We processed the data further by defining that a sleep interval started when 10 consecutive minutes were coded as 'asleep' and ended when 10 consecutive minutes were coded as 'awake' and adapting the original coding. Three different sleep variables were calculated using the definitions from Meltzer et al. (2012). Total sleep time is the total sleep duration per night. The variable 'wake after sleep onset' is a sleep fragmentation measure defined as the time infants spent awake between sleep onset in the evening and sleep offset in the morning. Sleep efficiency is the proportion of time that infants were asleep within the average time in bed (time between going to bed in the evening and getting up in the morning as indicated in the sleep diaries in hours).

8.2.3 Design and procedure

At months 4, 6, 8, and 10 (+/- 2 weeks) families received an envelope with a sleep diary and an actigraph, and were asked to record sleep data for seven consecutive nights. After this, families came into the lab to participate in eye tracking and interaction tasks. When arriving, the infant was first acclimatised to the experimenter and the lab setting before being tested. During testing, the infant sat on the caregiver's lap, about 50 cm away from the eye tracker and the screen. Black curtains surrounded the setting in order to keep the infant's attention on the screen. The experimenter applied a five-point calibration on the infant's gaze and then started the experimental protocol that included two other tasks. The memory task described here was shown after approximately 5 minutes and directly followed a short Sesame Street clip.

8.3 Results

I did not implement repeated measures ANOVAs in the analyses of data reported in this chapter but employed multilevel models using R and the NLME package (Pinheiro, Bates, DebRoy, Sakar, & Team, 2014). There are several advantages of multilevel models that fitted very well with the purpose of my analyses (see for instance in Hays, 1994; Kwok et al., 2008; Field, Miles, & Field, 2012). Multilevel analysis is a regression procedure that takes into account a potential hierarchical structure of the data set. For instance, in the longitudinal data from this study, it is possible to regard repeated measures as 'nested' within individual infants and conditions. Since we can assume dependence of outcome measures within a single infant it allows for clustering at this level as well as at a lower level such as age and condition. In other words, multilevel modelling offers flexible handling of variance-covariance structure. Moreover, and similarly important in this case, there is no need to have a balanced design or equally spaced measurements as in a normal repeated-measures ANOVA: it can deal with varying numbers of observations per infant. Finally, data can be integrated into one model instead of a number of separate tests. Hereafter, I will use the multilevel modelling procedure described in Field et al. (2012). In doing so, several models are at first defined, starting with a baseline model without predictors and adding one predictor after another in further models. Then those models are compared with each other to test which predictor significantly ameliorated the model.

8.3.1 Memory task

8.3.1.1 Memory: looking time differences and first saccade to the correct and incorrect side

A multilevel model with the within-subjects factors age (4, 6, 8, and 10), trial (first vs. second test trial), and side (correct vs. incorrect) and looking time as outcome variable was computed[1]. P-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question. There was a significant main effect of age, $\chi^2(3) = 8.91$, $p = .031$, and side, $\chi^2(1) = 5.48$, $p = .019$, but not trial, $\chi^2(1) = 1.04$, $p = .307$. Planned contrasts revealed that infants looked significantly longer to the correct side, $t(234) = 2.36$, $p = .019$, $r = 0.15$, and that 6-month-old infants looked overall longer during test trials than 4-month-olds, $t(90) = 2.88$, $p = .005$, $r = 0.29$. Since there were no significant differences between trials, looking times towards the correct and incorrect side were averaged over test trials for further analyses, and means are shown in Figure 8.2. Paired one-sided t-tests in the four groups indicate that infants looked significantly longer to the new number at 6 and 8 months, 6 months: $t(33) = 1.88$, $p = .034$, $r = 0.31$; 8 months: $t(35) = 2.20$, $p = .017$, $r = 0.35$, but not at 4 nor 10 months, 4 months: $t(26) = 0.61$, $p = .274$; 10 months: $t(35) = 0.52$, $p = .303$. This suggests that in general infants were not able to memorise the correct location at 4 months but succeeded a couple of months later. However, by 10 months

[1] I first entered as random effect 1|Participant/Age/Trial and then as predictors Age, Trial, and Side one after another.

infants are likely to have changed their strategy and searched elsewhere as soon as they realised that they could not find the toy in the expected location, and therefore looked equally long towards both sides.

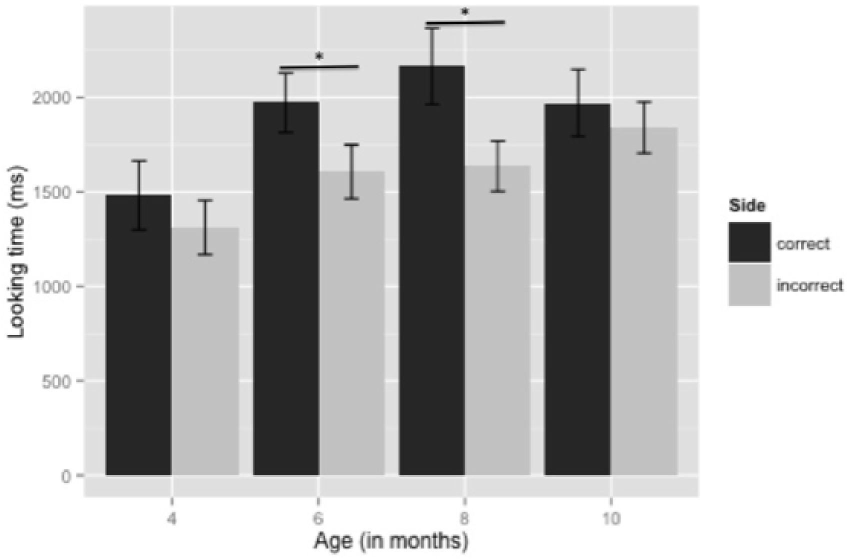


FIGURE 8.2: Mean looking times to the correct and incorrect side at 4, 6, 8, and 10 months with 95% CI errorbar. Differences in looking time were significant at 6 and 8 months.

The percentage of correct first saccades was smallest at 4 months and highest at 6 months (see Figure 8.3). Exact binominal tests analysing whether the probability of a correct response differed from chance were not significant for any of the age groups.

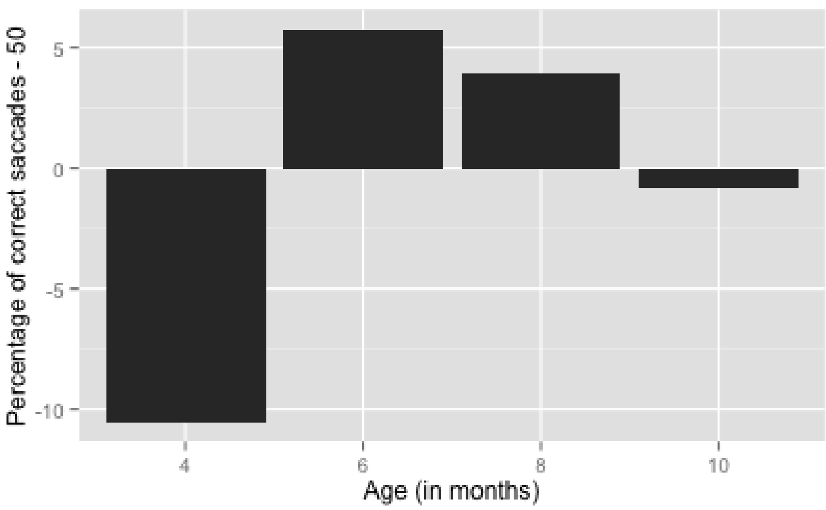


FIGURE 8.3: Percentage of correct first saccades in the test trials of the memory task.

8.3.1.2 Memory: development of looking time differences

I grouped the infants within ages into 'correct' and 'incorrect' lookers depending on whether the proportion of looking time to the correct side was more than .50. Table 8.1 displays the number of infants in the 'correct' and 'incorrect' groups at all ages.

TABLE 8.1: Number of infants grouped as correct ($>$ 50% of looking time to the correct side) and incorrect ($<$ 50% of looking time to the correct side) at all ages.

	4 months	6 months	8 months	10 months
correct	13	20	21	17
incorrect	14	14	15	19

In order to investigate whether infants who initially remembered correctly also did so later in development, I examined looking patterns at 6, 8, and 10 months of the infants who had been grouped as correct and incorrect lookers at 4 months. Interestingly, infants who looked correctly at 4 months did not do so when they got older (see Figure 8.4). The initial correct lookers even gazed significantly less to the correct side at 8 months compared to the initial incorrect lookers, $t(22) = 2.13$, $p = .044$, $r = 0.41$. This might be because infants who perform better than others in the memory task at an earlier age also change their strategy and start to search elsewhere at an earlier age than their peers.

8.3.2 Sleep characteristics

Descriptive statistics of the total night sleep time, wake after sleep onset, sleep efficiency, day time sleep, sleep onset latency, sleep onset regularity, and activity during sleep were presented in Chapter 5.

8.3.3 Sleep and memory

8.3.3.1 Concurrent associations

In order to investigate concurrent associations of sleep with performance in the memory task, I conducted several multilevel models with each having the memory group as outcome variable (incorrect = 0; correct = 1) and age as well as one of the sleep variables as the predictor. In the first model including 'total night sleep time', there was neither a significant main effect of age, sleep duration nor a significant interaction – infants

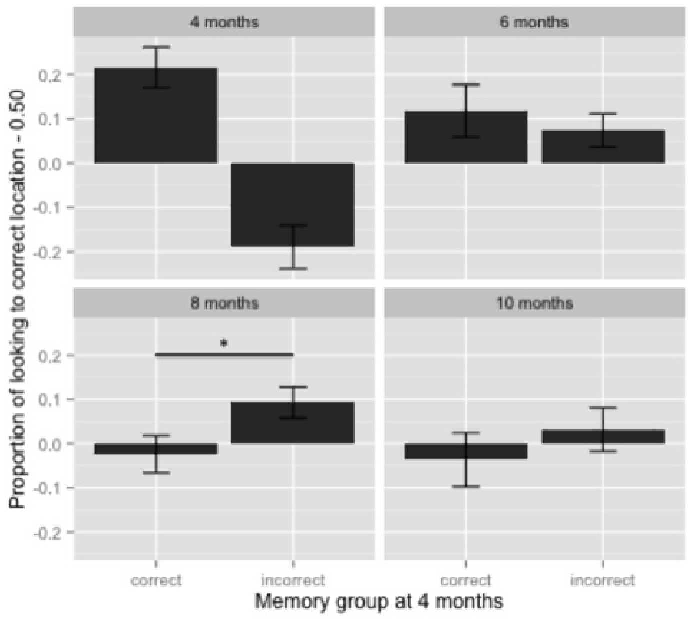
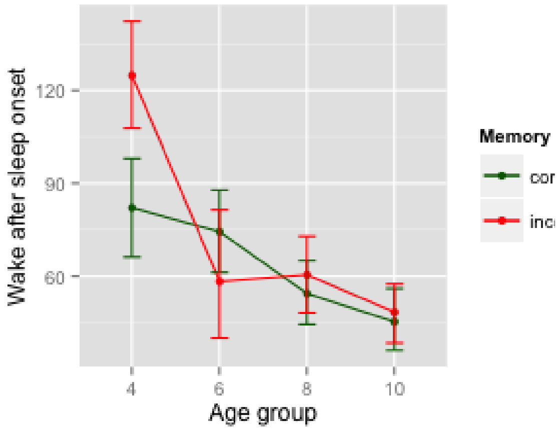


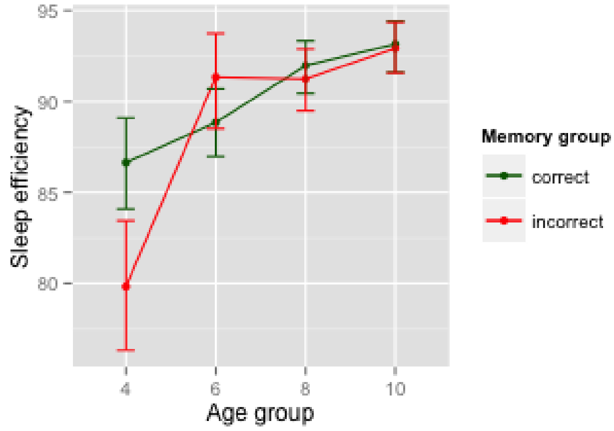
FIGURE 8.4: For infants who were grouped into correct and incorrect lookers at 4 months, this figure shows mean percentage of looking time at 4, 6, 8, and 10 months with 95% CI errorbar. At 8 months, infants who had looked correctly at 4 months, looked equally long to either side while infants who had looked incorrectly at 4 months, looked significantly longer to the correct side.

slept equally long in the two groups at all ages. Similarly, day sleep duration, sleep onset latency, and sleep onset regularity were not significantly related with the memory groups.

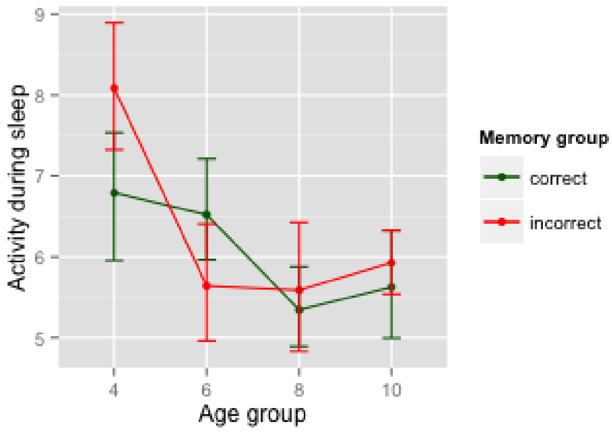
In the model including 'wake after sleep onset' there were no significant main effects of age and sleep but a significant interaction of age and wake time during the night, $\chi^2(3) = 9.46$, $p = .023$. At 4 months, infants in the 'correct' group woke up less during the night than infants in the 'incorrect' group, whereas there were no significant differences in 'wake after sleep onset' at 6 months between the groups, $t(75) = 3.03$, $p = .003$, $r = 0.33$ (see Figure 8.5a). Since the 'sleep efficiency' measure is calculated using 'wake after sleep onset', there was unsurprisingly a similar effect: I found no significant main effect of age and sleep efficiency but the interaction between age and sleep efficiency was significant, $\chi^2(3) = 8.34$, $p = .039$. At 4 months correct lookers slept more efficiently than incorrect lookers, but at 6 months there was again no difference between the groups regarding their sleep efficiency, $t(76) = -2.83$, $p = .006$, $r = 0.31$ (see Figure 8.5b). A model with activity during sleep revealed a marginally significant interaction of age and activity during sleep, $\chi^2(3) = 7.60$, $p = .055$, indicating that 4-month-old correct lookers were less active during sleep than at 6 months, $t(75) = 2.65$, $p = .009$, $r = 0.29$ (see Figure 8.5c).



(A) Wake after sleep onset in the 'correct' and 'incorrect' memory groups over ages.



(B) Sleep efficiency in the 'correct' and 'incorrect' memory groups over ages.



(C) Activity during sleep in the 'correct' and 'incorrect' memory groups over ages.

FIGURE 8.5: Those figures show different measures of sleep fragmentation and sleep duration for infants who looked more to the correct side (green) and infants who looked more to the incoorect side (red).

8.3.3.2 Longitudinal associations

In order to investigate longitudinal associations between sleep and memory, I correlated memory at 6, 8, and 10 months with the sleep measures at 4 months. To get a more sensitive measure than the dichotomous memory variable, I regrouped the infants according to their looking times in the memory task into 'correct lookers' when they had looked to the correct side for more than 55% and as 'incorrect lookers', when they looked less than

45% of the total looking time during test trials to the correct side. The remaining infants were grouped into the 'equally lookers'. Infants who slept shorter, $r = -.39$, $p = .025$, less efficient, $r = -.50$, $p = .003$, and woke up more often at 4 months, $r = .44$, $p = .011$, looked more correctly at 6 months (see Figure 8.6). The day sleep time, sleep onset regularity, sleep onset latency, and activity during sleep at 4 months were not correlated with later memory performance. There were no significant correlations between sleep variables at 4 months and memory performance at 8 and 10 months.

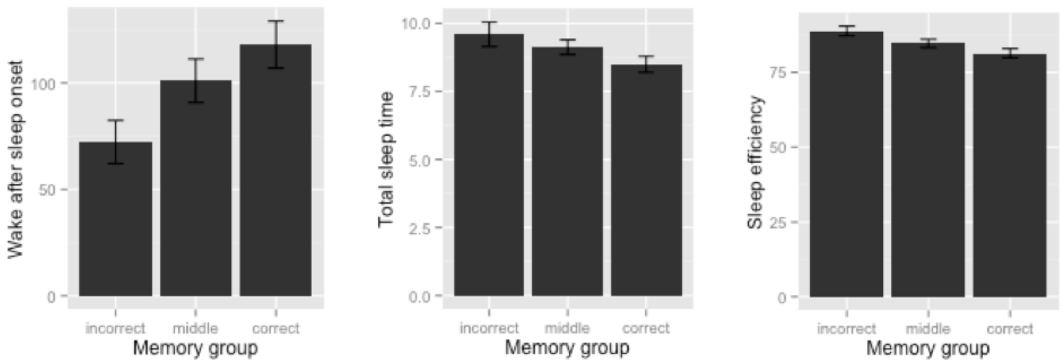


Figure 8.6: Differences in total sleep time, wake after sleep onset, and sleep efficiency in 4-month-old infants who look correctly, incorrectly or equally at 6 months with 95% CI errorbar.

8.4 Discussion

The aim of the study in this chapter was to investigate the concurrent and longitudinal relations between habitual night sleep and short-term memory in typically developing infants using a spatial indexing task and actigraphy. We found change over time in the memory task. Regarding the concurrent association between memory and sleep, 4-month-old infants with less fragmented and less active sleep performed better in the memory task at 4 months. Furthermore, more fragmented sleep and longer sleep duration at 4 months was related with better performance in the memory task at 6 months. In the following I discuss these associations and how they might be explained by individual differences in the strategy used in this particular memory task.

In the memory task, looking times during test trials indicate that overall 4-month-old infants had not made the auditory-visual mapping, i.e., they were not able to remember the correct location and therefore searched both sides. However, at 6 and 8 months, infants generally looked to the correct side, which suggests that they memorised the mapping. Only at 10 months was there again no difference between the looking times to both sides. When investigating infants who looked longer towards the correct side at 4 months, I found that they actually changed their looking pattern with age. This could be explained by a shift in strategy: infants who are able to remember the correct location at 4 months searched more on the correct side, but, at a later age, they actually searched in the other frame as well when they could not immediately find the target. However, infants, who could not remember the correct side at 4 months probably made this shift in strategy at a later point in time. I presume that the majority of the 10-month-old infants had adopted this new strategy therefore failed to look longer to the correct side.

It is conceivable that infants they failed to encode and remember the information in this task. This is very likely, since visual short-term memory capacities start off very limited at 4 months and increase significantly over the following months (Ross-Sheehy, Oakes, & Luck, 2003). The same seems to be the case for auditory short-term memory (Ross-Sheehy & Newman, 2015). However, there are other explanations why 4-month-old infants failed to look longer to the correct side and I will dwell on them in more detail in the general discussion of this thesis. For instance, they may not have been familiarised for long enough to do the auditory-visual mapping since very young infants need more exposure time than older infants (Richards, 1997; Courage & Howe, 2004).

Infants did not start their search significantly more often at the correct side as shown by the measure of first saccade. At 4 months, only 39% of the first saccades went to the correct side whereas some infants looked first at the incorrect side or searched the screen in an up-and-down movement. The percentage of correct first saccades was 56% at 6 months and slightly decreased again at 8 and 10 months. The hypothesis suggesting that 10-month-old infants searched the whole screen as soon as they did not find the toy in the correct location would indicate that infants' first saccade went to the correct location before they realised that there was no toy. One explanation why this was not the case is that infants at 10 months have a larger field of vision. Given that the screen was relatively small, one does not have to look to the correct side in order to see that no toy appears.

With respect to the sleep variables, I found an increase in total night sleep time and a decline in night sleep fragmentation measured by wake after sleep onset and sleep efficiency with age. This is in line with previous research (Sadeh et al., 1995; E. N. Henderson & Jennings, 2003; Sadeh, 2004).

Moreover, I found a concurrent relation between sleep fragmentation and short-term memory in young infants. Only very few studies have investigated the effects of sleep on cognition in infants, especially not in very young infants, and consequently it is difficult to embed these findings into a bigger picture. Less sleep fragmentation has, however, also been found to relate with better cognitive development in 10-month-old infants (Scher, 2005) and in older children (Sadeh et al., 2002; Bates et al., 2002) highlighting the fact that it is an indicator of better sleep throughout development.

Interestingly, more sleep fragmentation and less total night sleep at 4 months was related to better memory performance at 6 months, i.e., longer looking times to the correct side, which might first appear contrary with the concurrent sleep-memory-association at 4 months. However, bearing in mind that infants in our study probably shifted their strategy on the task, this effect is reasonable. Infants who already looked correctly at 4 months probably also started to search more actively and globally at an earlier age and therefore spent less time looking at the correct side by 6 months. Those infants slept more efficiently at 4 months. By contrast, infants who slept less efficiently at 4 months did not look longer to the correct side at that age and probably only started doing so at 6 months. Sleep efficiency is hence a marker for concurrent and longitudinal memory performance.

The concurrent and longitudinal associations between sleep variables and short-term memory could be explained by either (1) a direct effect of sleep quality on the ability to remember locations or (2) an indirect relation mediated by other factors that reflect both memory and sleep variables. Studies suggest that also other factors mediate the relation between sleep and cognition, such as the methods of recording, the timing of the measurements (Ednick et al., 2009), as well as influences such as socio-economic status, infant personality, and parenting styles (Mindell, Meltzer, et al., 2009; Bordeleau, Bernier, & Carrier, 2012; Sadeh et al., 2010, for review). Moreover, recent research suggests that the relation between sleep and cognition is much more bi-directional than previously thought. For instance Huber and Born (2014) discussed how the amount of slow wave sleep and episodic memory develop in parallel and that there is constant interaction between both processes. Consequently, it can be concluded that although sleep relates, as has been shown in this study, concurrently as well as longitudinally to memory performance, it is probably also associated to other aspects of development and can therefore serve as indicator.

8.5 Summary

As far as I know, it the first time that spatial indexing has been tested longitudinally over the first year of life and associated to infant sleep variables. Interestingly, there was not the expected amelioration in the memory task, but a U-shaped performance, which I explain in the following way. Infants normally start off without remembering the correct location. Then there comes a period when they remember and also search longer at the correct location. Finally, they probably remember but do not search longer at the correct location any more – maybe because they see that the toy does not appear at the correct side and therefore they search the whole screen. Another interesting result of this study was that infants differed in the timing of the shift from not remembering to searching correctly: those infants who searched correctly already at 4 months were less likely to do so at 6 months than those who searched incorrectly at 4 months. Regarding the association with habitual sleep, I found that more efficient and less active sleep at 4 months was related with better performance on the memory task at the same age. Later-on more efficient sleep might not have been a significant indicator for memory performance since the more advanced infants did not necessarily look more overall towards to correct location in the task. Hence, it is difficult to investigate the link between sleep and this memory task in the older age groups. Finally, there was a longitudinal association between early sleep variables and later memory. Infants who slept more efficiently and for longer during the night at 4 months performed better in the memory task at 6 months. In general, this study shows that we have to be careful with interpreting outcomes from 'cognitive tasks' in infant research when we do not know about the typical performance in those tasks over developmental time, which might not be linear.

Chapter 9

Sleep Patterns and Small and Large Number Processing

9.1 Introduction

Numerous studies have shown that humans spontaneously distinguish two different magnitudes under certain conditions (see Dehaene, 1997; Brannon, 2006; Piazza, 2010, for review). Many animals show similar number processing abilities to humans (see Meck & Church, 1983, for rats, Brannon & Terrace, 1998, 2000, for monkeys, and Colombo & Mitchell, 2008, for fish) and hence scholars suggest that number processing is controlled by a number module that is common to animals and humans (e.g. Gelman & Gallistel, 2009; Spelke & Kinzler, 2007). Thus the question rises whether this module is innate in human infants.

9.1.1 Two separate systems for numerical sensitivity

In fact, when adults are asked to indicate whether they perceive a difference between two presented numerosities or not, by for instance pressing a button, their reaction time depends not only on the distance between the two numerosities but also on their actual magnitude. Adults are normally very precise when estimating the magnitude of numbers up to 4 (Brannon, 2006; Piazza, 2010) but fail more often as soon as the number presented is larger than that (Trick & Pylyshyn, 1994). This effect led to the assumption that there exist two distinct processes that deal with number processing: the approximate 'analogue number system' (ANS) for the processing of large numerosities and the precise 'object-file system' (OFS) for the processing of small ones (Carey, 2009; Piazza, 2010, for review).

There is also evidence for two distinct number systems in adults from studies investigating brain activation. For instance, Hyde and Spelke (2008) examined event-related potentials in adults provoked by the visual presentation of small (1, 2, and 3 dots) and large arrays (8, 16, and 32 dots) and found effects of numerical range and cardinal value in the N1 component as well as effects of numerical ratio for large numbers only in the Pb2 component. In an fMRI-study by Ansari, Lyons, van Eimeren, and Xu (2007) two different brain regions were active when processing either small or large non-symbolic numerical arrays. This underlines the distinctive handling of small and large numbers in the brain and adds on weight to the hypothesis of two distinct systems.

9.1.1.1 The object-file system (OFS)

Crucial for numerical comparisons is the ability to quickly and accurately estimate the number of a set 'at a glance' without counting it, which is called 'subitizing' (Mandler & Shebo, 1982; Revkin, Piazza, Izard, Cohen, & Dehaene, 2008; Piazza, 2010). It is suggested that for each object of a small number set, an object-file is opened and information about each item of the set is stored. Consequently, an object-file is a representation of the real world item which is processed individually and which also contains individual information such as shape. Number is only represented implicitly.

9.1.1.2 The analogue number system (ANS)

Sensitivity to large numbers depends on the ratio between the two numerosities of the sets – it follows Weber's Law (Brannon, 2006; Libertus, Brannon, & Woldorff, 2011). Weber's Law states that perceptual stimuli are on a continuous dimension such as luminance, intensity of sounds or pressure, size, and weight and are differentiated in proportion to their objective difference. Weber's Law is also applicable to rather abstract characteristics such as number, space and time (Cantlon, Platt, & Brannon, 2009; Libertus et al., 2011). This means that if a two-fold change were needed to detect the difference between two magnitudes, one would be able to differentiate 10 from 20 or 40 from 80 but not 15 from 20. The ANS is consequently a language-independent representation of numerosity, targeting the approximate estimation of numerical magnitude. Research has shown that large number processing obeys the same law in all human adults, irrespective of their cultural background and language (Pica, Lemer, Izard, & Dehaene, 2004; Gordon, 2004). Furthermore, it is notation independent (Libertus, Woldorff, & Brannon, 2007) i.e. not affected by symbolic representation of numbers (e.g. Arabic numerals vs. a set of dots of a certain number).

One difficulty within the research of number processing is that it is also impacted by the way with which continuous variables of the presented number are dealt (Allik, Tuulmets, & Vos, 1991; Dakin, Tibber, Greenwood, Kingdom, & Morgan, 2012). When one changes, for instance, the number of black dots in a set without changing the size of the dots, contour length, total occupied area, and luminance are automatically modified as well. It is therefore crucial to use experimental designs and stimuli that minimise this effect – for instance by randomising item size in a familiarisation phase of a habituation/dishabituation paradigm and holding it constant during the test phase (Piazza, Izard, Pinel, Le Bihan, & Dehaene, 2004).

9.1.2 The development of number processing

Already from birth on, infants are sensitive to numerosity although they are much less accurate at numerical discrimination than adults (Feigenson, Dehaene, & Spelke, 2004, for review). Many scholars debate whether the two number processing systems actually develop as separate systems that become more and more accurate over time or whether they develop initiated by innate predispositions that are not number-specific (Karmiloff-Smith, 1996; Gelman & Gallistel, 2009). In other words: is numerical sensitivity a distinctive and innate domain or is it a developing module?

There is some evidence that small numbers are processed differently from large numbers from birth on. Although newborns can discriminate small numbers (Antell & Keating, 1983), they need a 1:4 ratio for large numbers (Izard et al., 2009). Furthermore, number discrimination in infancy has been shown to be more difficult when small and large numbers were compared, such as 3 vs. 6 or 2 vs. 4 (Xu, 2003; J. S. Lipton & Spelke, 2004; Feigenson & Carey, 2005; Wood & Spelke, 2005; Cordes & Brannon, 2009). Xu (2003), for instance, studied number processing in 6-month-old infants for 4 vs. 8 and 2 vs. 4 with stimuli that were controlled for continuous variables. The infants were able to detect the change in the large numbers (4 and 8) but not in the mixed ones that cross the small number processing boundary (2 and 4). In another study, 7-month-old babies needed a 4-fold change to detect a difference as soon as one number presented was smaller than 3 but only needed a two-fold change for numbers larger than 3 (e.g., Cordes & Brannon, 2009). Again this indicates that distinct processes developing at different rates underpin the two systems. An ERP-study including small and large numbers in 6-month-olds reported characteristic wave forms for each number system (Hyde & Spelke, 2011). Large numbers evoked a ratio-dependant later amplitude (P500) than small numbers (P400), which is indicative of different neural processing between small and large numerosities and another reason to assume that the OFS and ANS are distinct.

9.1.2.1 The development of the OFS

Newborns already discriminate small numbers, i.e. 2 and 3 (Antell & Keating, 1983). Studies investigating small number processing in the first year of life have shown this by using visual static stimuli (Starkey & Cooper, 1980; Antell & Keating, 1983; Clearfield & Mix, 1999; Xu, 2003), visual moving stimuli (Van Loosbroek & Smitsman, 1990), movements (e.g. puppet jumps, Clearfield, 2004; Wood & Spelke, 2005), auditory stimuli (Ruusuvirta, Huotilainen, Fellman, & Naatanen, 2009), and combinations of visual and auditory stimuli (Kobayashi, Hiraki, & Hasegawa, 2005; Jordan & Brannon, 2006). Those studies measured number processing, for instance, by looking time towards a visual numerical array after a change in number in a habituation task and usually not all infants showed the expected looking patterns. Indeed little effort has been made so far to understand the origin of those individual differences which could help to understand whether they arise by differences within an innate number system or whether they are driven by differences in non-specific predispositions.

9.1.2.2 The development of the ANS

With respect to large numbers, infants become increasingly accurate over the first years of life when differentiating two magnitudes (Brannon, 2006; Cordes & Brannon, 2008; Libertus & Brannon, 2009; Piazza, 2010, for review). Newborns are not able to differentiate a 2:3 ratio, i.e. 4 vs. 6 black dots (Antell & Keating, 1983), but can distinguish a 1:4

ratio (Izard et al., 2009). In the latter study, neonates were shown visual presentations of 4 or 16 objects together with auditory presentations of 4 or 16 syllables. The mean looking time was longer for the matching presentation. Studies with older infants often use a habituation/dishabituation paradigm in order to test whether infants are able to detect a change in numerosity. For instance, Xu and Spelke (2000) habituated 6-month-old babies with different sets of 8 or 16 black dots. When the infants looked 50% less during three consecutive trials compared to the first three trials, they alternately saw sets of 8 and 16 dots while their looking behaviour was recorded. Generally looking time significantly increased for the novel number, leading Xu et al. to conclude that infants were able to detect this two-fold change. In a follow-up experiment, they replicated the study but with a 2:3 ratio (8 vs. 12 or 12 vs. 16). This time, the infants did not look longer at the new number and consequently were not able to distinguish the 2:3 sets. Other studies using visual stimuli with the same 1:2 ratio but different numerosities found similar results (Xu, 2003; Brannon, Abbott, & Lutz, 2004; Xu, Spelke, & Goddard, 2005). Likewise vanMarle and Wynn (2009), J. S. Lipton and Spelke (2004), and J. S. Lipton and Spelke (2003) who employed auditory stimuli, and Wood and Spelke (2005) who presented movements (jumps of a puppet), found similar results. Also in a multi-modal representation of number, 6-month-old infants detected a mismatch of sights and sounds with a 1:3 and 1:2 ratio but not with a 2:3 ratio (Feigenson, 2011).

The ratio that infants are able to differentiate changed with age: by the age of 6 months, infants differentiate a ratio of 1:2 (Xu & Spelke, 2000; J. S. Lipton & Spelke, 2003), at 9 months a ratio of 2:3 (J. S. Lipton & Spelke, 2003; Libertus & Brannon, 2010); 4-years-olds succeed on ratios of 3:4, 5-years-olds of 4:5 and 6-years-olds of 5:6 (Halberda & Feigenson, 2008), whereas adults can discriminate a ratio of up to 7:8 (Pica et al., 2004). However, those studies report group data, not individual data, and not all infants and children actually show sensitivity to the numerical change.

Some studies have addressed the question of whether this change over time in numerical sensitivity derived from a refinement of an innate ANS or whether it represented the gradual development of a number module in interaction with other aspects of refinement. This issue amongst others was addressed by some studies looking at brain activation during number processing. Very young infants showed different brain activity in response to a change in number as opposed to a change in objects (Izard, Dehaene-Lambertz, & Dehaene, 2008). Izard et al. used a habituation/dishabituation paradigm and presented sets of coloured animal-like faces to 3-month-old infants while recording electrical potentials on the scalp. They either changed the number of the set or the objects after the habituation phase. A change of the objects only activated ventral temporal areas, whereas a change of number additionally activated parietoprefrontal areas. It is not clear whether this change was solely driven by the variation in number or in other continuous variables that co-varied, i.e. whether it is indicative of an innate number sense. In fMRI-studies with adults, number processing is particularly associated with the intraparietal sulcus, and there is evidence that already 4-year-old children recruit the same area (Cantlon, Brannon, Carter, & Pelphrey, 2006). As fMRI is not practicable with younger children, it is difficult to investigate in which brain circuits numerosity is processed earlier in life, when the brain is still less specialised, and how this changes over developmental time. Only one number study using near-infrared spectroscopy (NIRS) has been done with babies so far (Hyde, Boas, Blair, & Carey, 2010), where 6-month-old infants showed an earlier response to number change than to shape change. Here as well, number change activated in particular the right intraparietal region. In a study of Cantlon, Libertus, et al. (2009) ERPs were recorded in 7-month-old infants as well as in adults during numerical comparisons. In both age groups occipital-temporal and parietal brain regions were activated, but the infants also showed activation in the inferior frontal cortex. Cantlon et al. argued that this provides evidence of a core neural system which, early in development, is mediated by higher-order brain mechanisms. Both studies report that number processing activates similar areas in infants and in adults, but infants seem to be less specialised and recruit also other brain regions. Those findings cannot, however, adjudicate as to whether this specialisation of number processing is innate or not.

9.1.3 Distinctiveness of the ANS and OFS

It is currently debated whether the OFS exclusively represents small and the ANS exclusively large numbers (see Hyde, 2011). The most prominent reason to assume that small and large numbers are processed differently comes from infant research where number discrimination has been shown to be more difficult when, as mentioned earlier, comparisons cross the 3-item boundary, such as 3 vs. 6 or 2 vs. 4 (Xu, 2003; J. S. Lipton & Spelke, 2004; Feigenson & Carey, 2005; Wood & Spelke, 2005; Cordes & Brannon, 2009). Moreover, different brain activity in both adults and infants when processing small and large numbers support the hypothesis of two distinct systems (Ansari et al., 2007; Hyde & Spelke, 2008, 2011). Also, discrimination of small and large numbers is not correlated in adults (Revkin et al., 2008; Piazza, Fumarola, Chinello, & Melcher, 2011). However, there are studies demonstrating that under attentional load, adults' small number processing follows the laws of the ANS not of the OFS (Burr, Turi, & Anobile, 2010; Hyde & Wood, 2011). In an attempt to integrate these controversial findings, Hyde (2011) proposes that while large numbers are by default processed with the ANS, small numbers are only processed by the OFS if certain attentional conditions are fulfilled. Hyde therefore maintains that while the OFS and ANS are indeed distinct systems, they are not specialised for small and large numbers per se, but biased by attentional constraints. He nonetheless assumes that both systems are innately specified (see Figure 9.1, left-hand side).

Another possibility of how the two systems develop is to hypothesise that both are initially not clearly separated, but influenced by the same number-nonspecific biases, and become specialised over developmental time (see Figure 9.1, right-hand side). The aforementioned studies were done on 6-month-old or older infants, so that an earlier gradual process of specialisation could have been missed (compare to Karmiloff-Smith, 1996; Ansari & Dhital, 2006). Also, the infant studies did not investigate correlations between the two systems or whether the OFS and ANS related to the same early biases such as features of visual exploration.

9.1.4 The relation between sleep and number processing

No study on developing children or adults has hitherto examined the association between habitual sleep and performance in the number domain. The question is whether number processing is as a domain more or less unaffected by environmental or other factors that have an impact on cognition. Since number processing is biased by attentional load (Burr et al., 2010; Hyde & Wood, 2011) and since sleep affects attention, I hypothesise that there might be a link in infancy, too. However, if and how this link becomes apparent remains unclear.

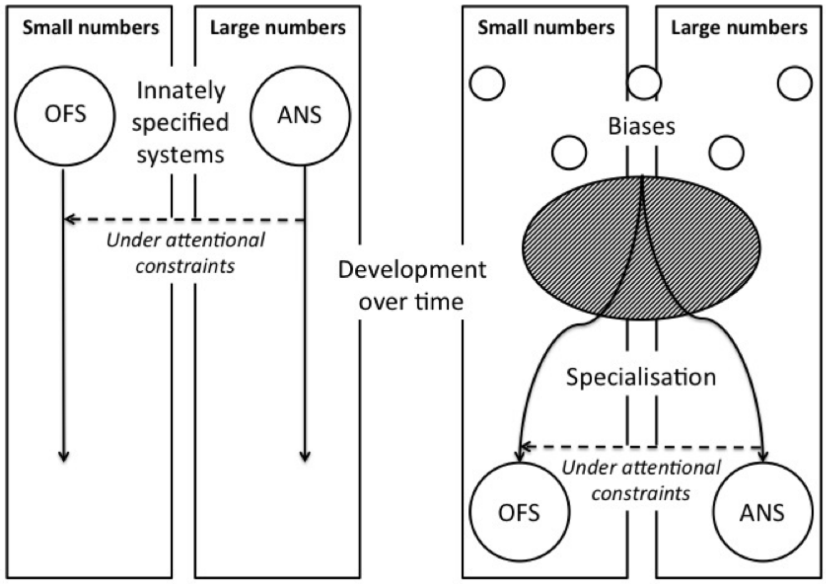


FIGURE 9.1: Schematic representation of two possible ways how the OFS and ANS develop. The figure on the left hand side represents a common view of number processing development where small and large number processing is distinct from birth (see Hyde, 2011). The figure on the right hand side represents an alternative model where both systems are related after birth, biased by other aspects of development, and only specialise over developmental time.

9.1.5 Aim of the present study

My aim is to shed more light on the issue of how number processing in the OFS and ANS **develops over time** in human infants. Therefore, in a longitudinal design, which assesses both small and large number discrimination in the same infants across the period between 4 and 10 months, I address the following four questions:

9.1.5.1 Is there a relation between the OFS and the ANS?

It is true that in adults, subitizing of small numbers and estimating of large numbers is unrelated (Revkin et al., 2008; Piazza et al., 2011). But adult outcomes are not necessarily a clue to infant starting points (Paterson, Brown, Gsödl, Johnson, & Karmiloff-Smith, 1999; Karmiloff-Smith et al., 2012). To our knowledge, studies have mainly targeted separate groups for each of the number systems and therefore did not explore possible correlations between the OFS and ANS, which is one aim of the current study.

9.1.5.2 Is numerical sensitivity a stable characteristic within an individual?

If the ANS and OFS are innate modules they should be relatively stable over time but little is known about individual stability of number processing abilities during development and not many researchers have investigated the relevance of individual differences.

There exist individual differences in numerical sensitivity in adults that also correlate with brain activity and probabilistic reasoning (Paulsen, Woldorff, & Brannon, 2010). A study with teenagers has also found individual variation that correlated with earlier mathematical achievement at primary school (Halberda, Mazzocco, & Feigenson, 2008). Those findins indicate that number sensitivity is stable and related to other aspects of cognition in older children and adults. There is just one study that investigated individual differences in very young children, while also examining stability (Libertus & Brannon, 2010). Six-month-old infants were presented with changing sets of black dots on two screens in their peripheral field of vision (one on the right and one on the left). On one screen the number of dots remained the same, but on the other screen the number changed with a certain ratio. Infants' looking times to either of the screens were recorded, and differences between the babies emerged. Twenty-three out of 32 infants preferred the screen with the changing number of dots when the ratio of the number change was 1:2, and only 7 out of 16 infants preferred looking at the screen with the changing number when the ratio was 2:3. In a follow-up study with the infants three months later, these differences remained stable. How these individual differences emerge and eventually change during development is still an unanswered question. Tracking them from earlier on in development could reveal whether they are relatively stable in very young infants or whether they only emerge after some time.

9.1.5.3 Are there features of visual attention that relate to the OFS and ANS?

We aim to investigate three features of visual exploration that could impact numerical sensitivity. The first is **attentional orientation**, which is the automatic first saccadic reaction to either of two numerical displays. Two different numerosities are presented alongside to each other and infants' very first look is coded. I hypothesize that their very first orientation will be towards the more complex, i.e., larger number, even if total looking time is greater for the smaller numerosity in some contexts. The second feature is **visual capture**, which I operationalise as the area of the screen where the infants look at when scanning a numerical array. Eye-tracking data revealed that infants with Down syndrome tend to scan an overall array and did better on large number discrimination (Karmiloff-Smith et al., 2012), whereas those with William syndrome whose tracking was confined to focussed areas performed better on small number discrimination (Van Herwegen, Ansari, Xu, & Karmiloff-Smith, 2008). So, visual exploration strategies may impact on number discrimination abilities. The third feature is the **mean fixation duration** while scanning a numerical array. S. V. Wass and Smith (2014) found that fixation durations in infancy were correlated with measures of cognitive control which could also impact early number processing.

9.1.5.4 Is there a link between sleep patterns and numerical sensitivity?

Finally, my aim is to explore the association between sleep variables and numerical sensitivity within small and large number processing.

9.2 Methods

9.2.1 Number processing task

A familiarisation paradigm was used to test numerical sensitivity to small and large numerosities (see Figure 9.2). At the start of the task and in between the nine trials, an attention grabber was presented at the centre of the screen, with trials only beginning once the infant fixated the grabber. All trials lasted 5 seconds. At the beginning of each familiarisation phase, a single big circle was presented during two trials that included a defined number of dots (e.g., 8), in order to record looking patterns when infants visually explored numerical arrays. Subsequently, I familiarised infants with this number (e.g., 8) by presenting two adjacent big circles each including a set of the same number of dots with different spatial arrangements for 5 consecutive trials. Only in the test trial did the number of dots change within one of the circles (e.g., 8 dots on one side and 16 on the other).

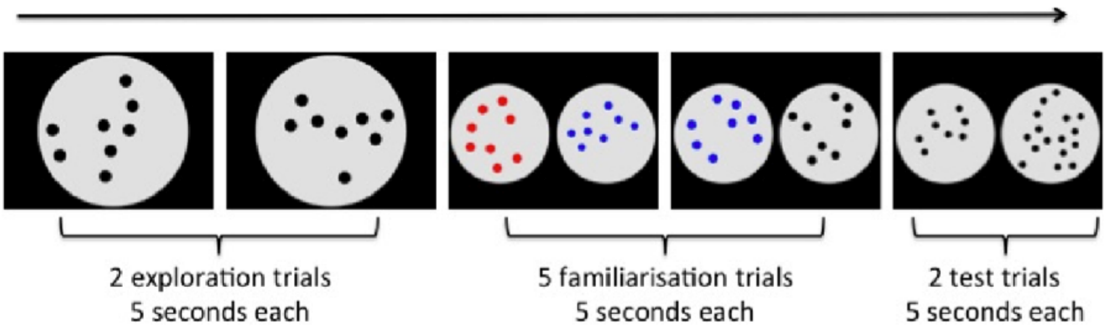


FIGURE 9.2: Illustration of the numerical sensitivity task.

Small numbers were tested at all ages with 2 (familiarised) vs. 3 (test) and 3 vs. 2 small dots (2:3 ratio). The large number condition changed with age: 8 vs. 16 and 16 vs. 8 (1:2 ratio) was tested in the 4- and 6-month-olds; 8 vs. 12 and 12 vs. 8 (2:3 ratio) was tested in the 8-month-olds, and 8 vs. 10 and 10 vs. 8 (4:5 ratio) was tested in the 10-month-old infants. This was done because sensitivity to large numbers displays changes across the first year of life.

9.2.2 Participants

Forty infants (21 females) with an average of 16 weeks and 2 days (age range: 14 weeks - 18 weeks) were included in the final sample of the testing at Time 1 and subsequently followed up every 2 months. Eye-tracking data were not collected from one infant at 8 and 10 months because of illness and from another infant at 10 months since the family had moved away. Furthermore, at each testing point and for each condition, a few data points are missing from some infants because they did not complete the whole testing procedure. Also prior to the analyses of the looking times, I excluded all test trials with less than 500ms of recorded looking time that were caused by equipment failure or fuzziness of the infant (the exact sample sizes for each condition, and age group are listed in Table 9.1).

9.2.3 Stimuli

The stimuli for the numerical sensitivity task were created using a program developed by Piazza et al. (2004) that is designed to vary item size during familiarisation trials and to control for total luminance during test trials. They consisted of one big light grey circle on a black background with a previously defined number of smaller black, blue, or red

Table 9.1: Number of infants included in the analysis per age and condition, with number of infants tested in each condition at each age in brackets.

	4 months	6 months	8 months	10 months
2 vs. 3	27 (35)	22 (22)	29 (30)	23 (23)
3 vs. 2	18 (22)	25 (25)	26 (26)	15 (17)
8 vs. 16/12/10	14 (16)	33 (34)	35 (36)	34 (34)
16/12/10 vs. 8	14 (15)	32 (32)	32 (33)	35 (37)

dots inside the circle. Colourful stimuli were chosen to make the task more interesting for infants. The dot radii varied randomly between sets during familiarisation trials but were controlled during test trials. Each set within a circle was randomly taken from a sample of 30 previously designed sets during familiarisation trials. The very first two trials as well as the sets in the test trails were, however, pre-selected in order to avoid unusual patterns such as a face-like array when there were three dots; in these test arrays all stimuli were black so as to avoid any bias because of colour preference. The side of the screen on which the new number was presented during test trials was randomised.

9.2.4 Data analysis

Number discrimination abilities were assessed through the averaged proportion of time each infant spent looking at the side of the screen where the new number was presented. The first feature of visual exploration that was later correlated with the numerical sensitivity measure – the attentional orientation – was the 'correctness' of the first look in each test trial. If infants gazed first towards the new number, the trial was coded with 1 and if their first saccade was towards the familiarised number, it was coded with 2. All trials with looks that did not clearly go in one direction or that did not start in the middle of the screen were excluded from analyses. Codings were done using a matlab script that defined the direction of the first saccade. Furthermore, I recorded the average area that the infant had visually explored ("seen") in the first two familiarisation trials, quantified in number of pixels. For this, each pixel on a 1024 x 768 screen was surrounded by a square of 60 x 60 pixels that was also marked as "seen". Figure 9.3 shows one possible exploration pattern (1) and the area that was considered as "seen" in this analysis (2). Fixation durations were coded with Grafix (de Urabain, Johnson, & Smith, 2014). Data were analysed using R and the NLME package (Pinheiro et al., 2014).

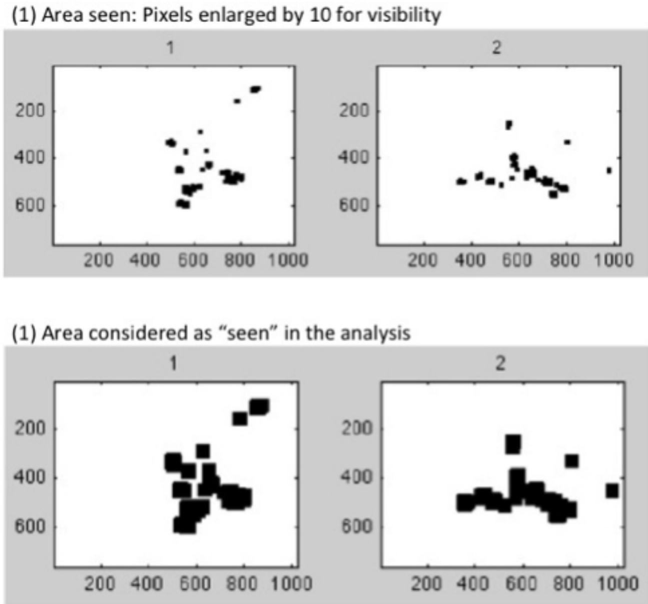


Figure 9.3: Example for captured area in the first two familiarisation trials for condition 1 in a 4-month-old infant.

9.3 Results

I first analysed looking times to either side during test trials to describe infants' ability to distinguish numerical arrays for small and large numbers. Then – in order to understand whether both number systems are separate systems or developing in interaction –, I explored correlations between small and large number processing, individual stability of the measures, and correlations between number discrimination and aspects of visual exploration patterns and number processing. Finally I explored associations between sleep variables and number discrimination.

9.3.1 Descriptive statistics of numerical sensitivity

As can be seen in Figure 9.4, across conditions infants preferred the larger number irrespective of whether it was new or familiar, e.g., they generally preferred looking at an array of 3 instead of 2 dots, regardless of whether they had been familiarised with 2 or 3.

Proportions of looking time in the small number conditions were examined using a multilevel model with the within-subjects factors condition (2 vs 3 and 3 vs. 2) and age

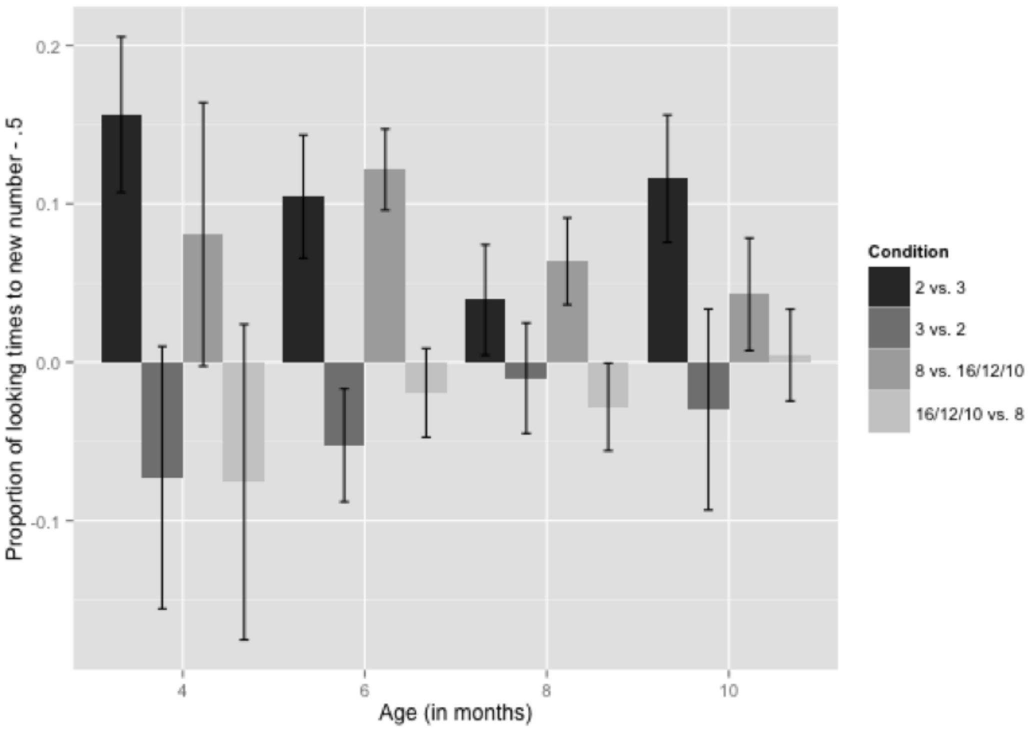


FIGURE 9.4: Mean proportion of looking time towards the new number with 95% CI error bars for each condition and age.

(4, 6, 8, and 10 months)[1]. P-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question. Age did not have a significant effect on the proportion of looking time to the correct number, $\chi^2(3) = 1.44$, $p > .249$, but condition significantly predicted the looking times, $\chi^2(1) = 16.85$, $p < .001$. The interaction of age and condition was non-significant, $\chi^2(3) = 4.163$, $p = .235$. Planned contrasts revealed that, overall, infants looked significantly less to the correct side in the 3 vs. 2 than in the 2 vs. 3 condition, $b = -0.14$, $t(326) = 4.15$, $p < .001$, $r = 0.57$. Since the model only compared the two conditions with each other, but not how each one differed from chance, I did a series of one-sided t-tests. Infants look differently from chance in the 2 vs. 3 condition at 4 months, $t(26) = 3.18$, $p = .002$, 6 months, $t(21) = 2.21$, $p = .019$, and at 10 months, $t(22) = 2.43$, $p = .012$.

I used a similar model for large numbers as for the small number analysis including the within-subjects factors condition (8 vs. 10/12/16 and 10/12/16 vs. 8) and age (4, 6, 8, and 10 months). Again, age did not significantly predict the proportion of looking time to the new number, $\chi^2(3) = 1.83$, $p > .249$. However, condition had a significant effect,

[1] I entered as random effect 1|Participant/Age and as predictors Age, Condition, and the interaction of Age and Condition one after another.

$\chi^2(1) = 14.44$, $p < .001$. There was no significant interaction of age and condition, $\chi^2(3) = 3.13$, $p > .249$. Contrasts revealed again that infants looked significantly longer towards the side with the new number when they had been familiarised with the smaller number, i.e. 8, and tested with the larger number, i.e. 10, 12 or 16, than vice versa, $b = 0.10$, $t(79) = 3.87$, $p < .001$, $r = 0.40$. Again I did one-sided t-tests to investigate how looking times differed from chance. At 6, 8, and 10 months infants looked significantly longer to the new number in the 8 vs. 16/12/10 conditions, 6 months: $t(32) = 4.75$, $p < .001$, 8 months: $t(34) = 2.47$, $p = .009$, 10 months: $t(33) = 1.67$, $p = .052$.

9.3.2 Individual stability

I tested individual stability of looking times by computing paired correlations between ages. The proportion of looking time was mainly positively related but not significant. When repeating the analysis with only data from the first test trial, there was a significant correlation in the large number conditions between 8 and 10 months, $r = .32$, $p = .018$, 95% CI [0.05, 0.54].

9.3.3 Relation between OFS and ANS

The correlation between the small and large numbers conditions was significant at 4 months, $r = .68$, $p = .002$, 95% CI [0.30, 0.87], but not in the older age groups, 6 months: $r = .01$, $p > .349$, 8 months: $r = -.19$, $p = .206$, 10 months: $r = -.14$, $p > .249$. Fisher r-to-z transformation showed that the correlation coefficients at 4 and 6 months differed significantly, $z = 2.58$, $p = .01$.

9.3.4 Relation between the systems and features of visual exploration of numerical arrays

The three extracted features of visual exploration are presented in Figure 9.5.

9.3.4.1 Attentional orientation

Data from the first look in the test trials reveal a similar pattern to the proportion of looking time during test trials: at all ages infants' first look was more often directed

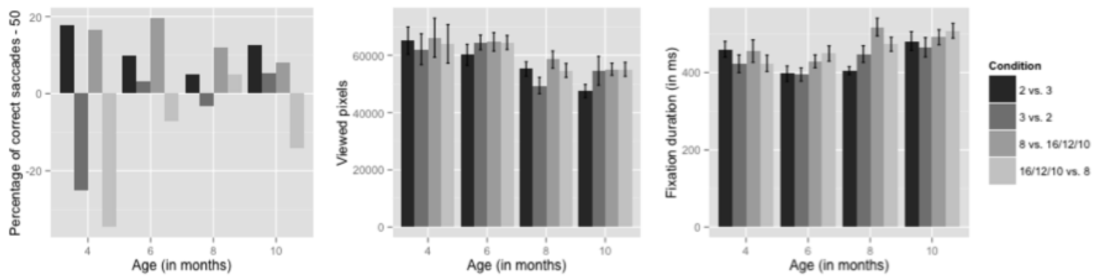


FIGURE 9.5: Proportion of correct first saccades in the test trials as well as mean captured area and mean fixation durations with 95% CI during the first two familiarisation trials over conditions and ages.

towards the larger number. Regarding small numbers, an exact binomial test showed that infants looked significantly more often towards the correct side in the 2 vs. 3 condition at 4 months, $p = .043$, 95% CI [51, 100], probability of success: 0.68, but not at other ages (p-values ranged between .07 and .28). Also in the 3 vs. 2 condition, infants only looked significantly more often to 3 at 4 months, $p = .038$, 95% CI [0, 48], probability of success: 0.25 (p-values in the other ages $> .249$). An exact binomial test analysing the first looks in the large number conditions 8 vs. 16 and 16 vs. 8 showed that 4-month-old infants looked more often at 16 in the 16 vs. 8 condition, $p = .011$, 95% CI [0, 41], probability of success: 0.15. At 6 months, first saccade was more often directed towards 16 in the 8 vs. 16 condition, $p = .005$, 95% CI [57, 100], probability of success: 0.70. Eight-month-olds' first saccades were more often oriented to the array of 12 in the 8 vs. 12 condition, $p = .012$, 95% CI [0, 41], probability of success: 0.62. Finally, the first saccade measure in the 10-month-old infants showed that infants preferred arrays of 10 in the 10 vs. 8 conditions, $p = .028$, 95% CI [0, 48], probability of success: 0.34. Taken together, the first saccade measure suggests that infants might be sensitive to large number differences at all ages for the conditions tested.

A multilevel model was created to investigate whether the first saccade measure predicted the proportion of looking time to the new number. Age (4, 6, 8, and 10 months) and condition (2 vs. 3, 3 vs. 2, 8 vs. 10/12/16, and 10/12/16 vs. 8) were included as within-subject factors. The first look significantly predicted the proportion of looking time, $\chi^2(1) = 272.71$, $p < .001$, and planned contrasts revealed that infants looked longer overall to the side where they had directed their first saccade, $b = 0.36$, $t(285) = 18.21$, $p < .001$.

9.3.4.2 Visual capturing

In a multilevel model with the within-subjects factor age (4, 6, 8, and 10 months) and condition (2 vs. 3, 3 vs. 2, 8 vs. 10/12/16, and 10/12/16 vs. 8), age had a significant effect on the explored area, $\chi^2(3) = 15.50$, $p = .001$, but not condition, $\chi^2(3) = 5.14$, $p = .162$. Planned contrasts revealed that infants explored less area of the screen as they got older, 4 vs. 6 months: $b = 4833.44$, $t(105) = 2.25$, $p = .046$, 6 vs. 8: $b = 9734.99$, $t(105) = 4.19$, $p < .001$, 8 vs. 10: $b = 5683.71$, $t(105) = 2.86$, $p = .008$.

Another model, with age (4, 6, 8, and 10 months) and condition (2 vs. 3, 3 vs. 2, 8 vs. 10/12/16, and 10/12/16 vs. 8) as within-factors but with age, condition, and proportion of looking time as outcome variables and explored area as a predictor variable, showed that the captured area did not significantly predict percentage of looking time, $\chi^2(1) = 1.73$, $p = .188$.

9.3.4.3 Fixation Duration

With respect to fixation durations, data from infants with less than 7 codable fixations in one condition were excluded from the analyses (in total 5 infants at 4 months, 15 infants at 6 months, 11 infants at 8 months, and 10 infants at 10 months for one condition respectively). A repeated measures model but with fixation duration as outcome measure and age and condition as within-subject factors showed that age, $\chi^2(3) = 23.30$, $p < .001$, as well as condition, $\chi^2(3) = 23.98$, $p < .001$, had significant effects on mean fixation durations, and the interaction of age and condition was marginally significant, $\chi^2(9) = 16.27$, $p = .061$. Contrasts revealed that fixation durations were longer in infants older than 6 months, 4 vs. 6 months: $b = 7.97$, $t(101) = 0.81$, $p = .42$, 6 vs. 8 months: $b = 43.91$, $t(101) = 4.24$, $p < .001$, 8 vs. 10 months: $b = 31.44$, $t(101) = 3.60$, $p < .001$. Also, they were shorter when infants were exploring smaller numbers (2 or 3) compared to larger numbers (10/12/16 or 8), $b = 20.64$, $t(186) = 5.00$, $p < .001$. Furthermore, there was an interaction between the number display (small vs. large) and age (4 vs. 6) in young infants, $b = -18.47$, $t(186) = -2.25$, $p = .026$.

Mean fixation durations were unrelated to percentage of looking time, $\chi^2(1) = 1.64$, $p = .20$.

9.3.4.4 Relation within the features of visual exploration

In order to investigate whether the looking patterns in the familiarisation trials predicted numerical sensitivity in the test trials, another linear mixed effect model was computed, with the within-subjects factors age (4, 6, 8, and 10 months) and condition (2 vs. 3, 3 vs. 2, 8 vs. 10/12/16, and 10/12/16 vs. 8), the outcome variable first saccade, and age, condition, and area as the predictor variables. Explored area predicted the direction of the first saccade marginally significantly, $\chi^2(1) = 3.61$, $p = .057$. Irrespective of age, infants were more accurate in their first saccade when they had explored a smaller area, $b < 0.01$, $t(262) = 1.89$, $p = .059$.

9.3.5 Association between number processing and sleep

9.3.5.1 Concurrent associations

Similar to the analyses in Chapter 8, where I investigated the relation between sleep and short-term memory performance, I conducted a series of multilevel models in order to examine whether there were any associations between habitual sleep and performance in the number processing task at one point in time. First of all, I again divided the infants into two groups regarding their looking pattern in the numerical sensitivity task. All infants who looked more than 50% of their looking time during both test trials to the new number were grouped into the 'correct' lookers category and the infants looking less than 50% towards the new number were groped into the 'incorrect' lookers category. Exploratory plots revealed a linear trend rather than an interaction between age and sleep variables. In the graphs, the greatest difference emerged for some sleep variables at 4 months. But, unlike in the results on memory and sleep, this effect for some sleep variables had not completely vanished at 6 months, but was just less strong. Therefore, I included age as a continuous variable into the model and not as a factor. Again, a first baseline model was defined including only the intercept and the group (correct and incorrect) as outcome variables. The participants were nested within the age group and the conditions. Then age (4 to 10 months), condition (2 vs. 3, 3 vs. 2, 8 vs. 16/12/10, 16/12/10 vs. 8), and one sleep variable were entered one after another. Finally, all interactions were added one at a time and all models were compared with the previously defined model. Pre-defined contrasts were determined: I compared the conditions on small numbers with those on large ones (1), I compared the condition 2 vs. 3 with the 3 vs. 2 condition within the small numbers only (2), and I compared the 8 vs. 16/12/10 with the 16/12/10 vs. 8 condition within the large numbers only (3).

There was no significant association between numerical sensitivity and total night sleep duration, day sleep duration, sleep onset latency, sleep onset regularity, and activity during sleep. With respect to 'wake after sleep onset', there was a significant main effect of condition, $\chi^2(3) = 24.06$, $p < .001$, and a significant interaction between 'wake after sleep onset' and condition, $\chi^2(3) = 7.92$, $p = .047$. Infants who woke up less often during the night looked longer to the new number in the 8 vs. 16/12/10 conditions than in the 16/12/10 vs. 8 conditions and longer to the new number on the 3 vs. 2 than in the 2 vs. 3 condition, for familiarisation with 2 or 3 (small numbers): $t(236) = -1.93$, $p = .055$, $r = 0.12$, for familiarisation with 8 or 16/12/10 (large numbers): $t(236) = 1.71$, $p = .088$, $r = 0.11$ (see Figure 9.6a).

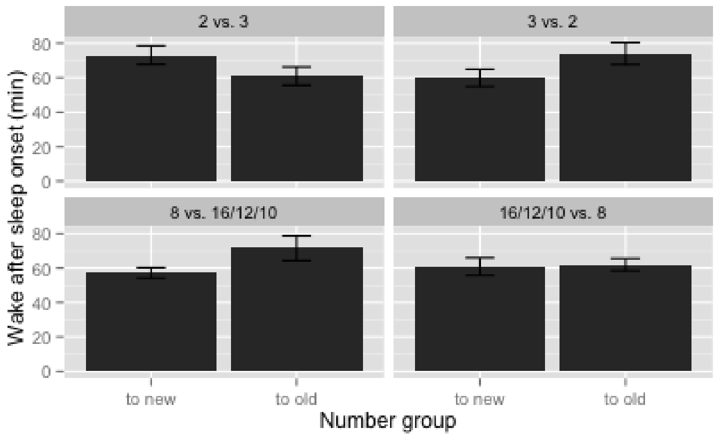
Similar to 'wake after sleep onset' there was a significant interaction between sleep and condition for sleep efficiency, $\chi^2(3) = 8.28$, $p = .040$. Infants who slept more efficiently during the night looked longer to the new number in the 8 vs. 16/12/10 condition than in the 16/12/10 vs. 8 condition, $t(236) = -2.14$, $p = .033$, $r = 0.14$ (see Figure 9.6b).

9.3.5.2 Longitudinal associations

Similar to the analyses on in the Chapter on memory and sleep, I first grouped infants into those who looked longer and those who looked less than 50% to the new number. Then I compared the groups at 6, 8, and 10 months with repect to their sleep variables at 4 months. However, there were no significant differences, which suggests that sleep variables revealed no long term associations with number processing.

9.4 Discussion

I replicated previous findings both that young infants are already sensitive to changes in small numbers (Xu, 2003) and that they develop a ratio-dependent acuity over time for discriminating large numbers (Xu & Spelke, 2000; J. S. Lipton & Spelke, 2003; Libertus & Brannon, 2010). Moreover, I found individual stability in large number processing in the



(A) Wake after sleep onset in the group of infants who looked more to the new or to the old number at 4, 6, 8, and 10 months.

(B) Sleep efficiency in the group of infants who looked more to the new or to the old number at 4, 6, 8, and 10 months.

Figure 9.6: Infants who look to the correct side 4 months have less fragmented and less active sleep.

older infants. To our knowledge, Libertus and Brannon (2010) is the only other study that examined individual stability of the ANS in infants. They reported correlations between looking times at 6 and 9 months. It may be that some individual stability in numerical sensitivity to large numbers is only beginning to emerge during the first year of life, which suggests that this reflects a gradual process of specialisation as opposed to an initially separate system.

Research has shown that in adults the ability to subitize and the ability to estimate are not correlated, but operate as independent numerical systems for the processing of small and large numerical displays (Revkin et al., 2008; Piazza et al., 2011). In the present study, I asked whether this is already the case in early development. Two possible hypotheses are discussed: (1) that the OFS and ANS are separate from birth (see Hyde, 2011); and (2) that both systems are not clearly separate, influenced by the same early biases, and only become specialised over developmental time.

Discrimination of small and large numbers was positively correlated in the youngest age group. However, this correlation can be explained by both hypotheses: (1) the systems could still be separate but, because the attentional load for this type of tasks is higher in very young infants, small number discrimination is at first underpinned by the ANS. Thus, the OFS may only gradually acquire a dominant role for small number representation in older infants. This hypothesis is related to findings that very young infants lack the necessary attentional abilities to detect, integrate, and store distinct information regarding single items (Ross-Sheehy et al., 2003; Gerhardstein, Shroff, Dickerson, & Adler, n.d.). Consequently, when the infants in our study were only 4 months old, they were likely to have needed higher attentional and memory capacity to open and store object-files and therefore, instead of the OFS, they relied on the ANS even in the case of small number discrimination. (2) Regarding the second hypothesis, the correlation in very young infants could be due to both systems not being clearly specialised at that age.

In order to investigate whether early biases influence number processing, I examined three features of visual exploration. Regarding the first, attentional orientation, when tested with small numbers infants gazed more often towards the larger number only at 4 months. For large numbers, the larger number was preferred at all ages. Again, this could be explained by both hypotheses: (1) very young infants could process small numbers with the ANS and not the OFS in this type of task (e.g., because of a higher attentional load that very young infants require) and only the ANS is related to first saccade, or (2) both systems are not clearly separate early in development and both relate to orientation.

The captured area decreased with age but did not change between conditions. However, mean fixation durations differed for ages and conditions: they were longer in older infants and shorter when infants were looking at smaller numbers indicating that they made more fixations when looking at small number displays. This speaks against the notion that infants use parallel individuation of small numbers. Since the difference between small and large numbers was not found in the 4-month-old infants, both hypotheses could still hold.

The first saccade measure predicted small and large number processing, i.e., the proportion of looking time, across ages. The question arises, however, whether the first saccade is an automatic and reflexive orientation towards more complex arrays or whether it constitutes part of the number sense. If first saccade were part of an independent number system, it could be used as a measure to demonstrate sensitivity at earlier ages than has hitherto been assumed when analysing looking time. However, if it is only a reflexive orientation that is not related specifically to number processing, this suggests that the OFS and ANS probably do not develop completely independently of other aspects of cognition. Infants' attention may be directed by features of images such as complexity that also happens to be characteristic of numerical arrays. Individual differences in this non-numerical ability could then influence numerical sensitivity over time. I also found some evidence that the way in which infants explored the numerical display, i.e. their eye-tracking patterns, affected their first saccade. The relation between first saccade and number processing abilities, as well as with characteristics of exploration, indicates that there is interaction between various aspects of visual attention and number processing in early development. That both systems were related to the same features supports the second hypotheses, i.e. the systems are not clearly separated in early development.

Regarding the association between sleep variables and numerical sensitivity, there was a relation between sleep fragmentation / efficiency and performance in the number task, which points in the same direction as the results on the memory task (see Chapter 8). In particular for large number processing, infants with more fragmented / less efficient sleep looked longer towards the larger number, i.e., there was a significant interaction of sleep and condition. One may now argue that this does not demonstrate that infants who sleep better are also better at number processing since there was an interaction between sleep and condition but no consistent main effect of sleep. Only in the 8 vs. 16/12/10 condition did better sleeping infants look longer towards the new number (i.e., 16/12/10) but they showed the opposite effect in the 16/12/10 vs. 8 condition and looked more towards the old number. However, there are two reasons why I still feel justified in arguing that less fragmented sleep is associated with higher numerical sensitivity. First, I showed before that infants generally prefer the larger number irrespective whether they had been familiarised with the same or a smaller one. I argued that infants who can distinguish the numbers show a greater and systematic preference for one of them compared to infants who cannot differentiate the two numbers. Second, when examining the figures (Figure 9.6b and 9.6a) more closely, it is evident that there is a more prominent difference in sleep with respect to the conditions when infants were familiarised with the smaller and tested with the larger number, e.g., 8 vs. 16/12/10. In those conditions looking to the larger number and looking to the new number is the same.

9.5 Summary

To the best of our knowledge, this is the first time that small and large number processing has been tested simultaneously and longitudinally in infancy as well as was examined with respect to its relation to characteristics of visual exploration and infant sleep variables. I replicate the finding that infants are already able from early on to differentiate small numbers, i.e. 2 vs. 3, and that they become increasingly sensitive to large number differences, i.e. 8 vs. 16 or 12. Looking times in the OFS and ANS were positively correlated only at 4 months and individual stability only emerged in older infants. Also, I showed that number processing was related to the initial saccade in test trials where two different numbers were displayed next to each other. Moreover, this first saccade was related to other aspects of visual exploration. That indicates that small and large number processing is influenced by the same number-unrelated visual predispositions over development, becoming stable later during the first year of life. Finally, infants who had a less fragmented / more efficient night sleep were better at number discrimination.

Chapter 10

Sleep Patterns and Visual Attention

10.1 Introduction

From birth, attentional biases influence the features of the environment on which infants focus on and what they are processing (Scerif, 2010, for review). The capacity to sustain attention for longer periods of time or to react quickly and accurately is related to sleep quality in adults (e.g., Banks & Dinges, 2007). Whether this is also the case for infants has not hitherto been investigated despite the fact that it could have important implications for reducing sleep problems during the first year of life. In this chapter, I examine longitudinally whether infants' sleep quality is related to both reaction time and disengagement.

10.1.1 Association of attention and sleep

Studies with adults have extensively shown that there is a strong link between sleep and attention. Sleep-deprived individuals generally experience decreased sustained attention and lapses of attention (Banks & Dinges, 2007) as well as an overall slowing down, a higher error rate, and attention lapses for more lengthy periods (Lim & Dinges, 2008). Moreover, greater performance variability is evident in sleep-deprived individuals compared to participants who had slept normally (Doran et al., 2001). Converging evidence suggests that sleep is important for sustaining the functional integrity of the fronto-parietal networks and the default mode network in the brain that support sustained attention (Drummond et al., 2005; Chee & Tan, 2010). Sleep deprivation affects this network which makes it more difficult for people to maintain sustained attention at the maximum level.

Regarding habitual sleep, Van Dongen and Dinges (2005) found that chronic sleep restriction had a similar effect as total sleep deprivation on a psychomotor vigilance task. This suggests that the habitual sleep pattern that adults adopt can affect his/her attention. For instance, people who are woken up more often during night sleep are sleepier the next day as well as have decreased mood, mental flexibility, and sustainsed attention (Martin et al., 1996). In a large study from Neylan et al. (2010), sleep variables of police academy recruits were recorded for a week using actigraphy, with the participants being tested on several occasions on a psychomotor vigilance task. The probability of a lapse decreased as a function of each additional hour that the person had slept the night before testing. Another study found differences in brain activity during a change detection task in habitual short sleepers (less than 6 hours per night) and normally long sleeping people (8 hours) (Gumenyuk et al., 2011). Furthermore, detrimental effects of sleep deprivation have been reported in the context of different kinds of attention tasks such as tests for simple and complex attention or working memory (Lim & Dinges, 2010). Nevertheless, a meta-analysis also revealed individual differences in adults regarding the vulnerability caused by sleep deprivation (Lim & Dinges, 2010).

Since attention plays a vital role during development – it affects crucially what the child is processing – the need to understand the role of sleep in this context is considerable. If habitual sleep shaped attentional abilities in a similar way as in adults, infants and children with sleep problems would have a reduced attention span, could absorb less information, and would as a result learn less well, which could lead to long lasting consequences. Because it is not ethical to experimentally induce sleep fragmentation in infants, studies have focused on habitual sleep, infants with sleep problems or sleep apnoea, as well as investigated sleep in children with attention difficulties, e.g., ADHD.

Generally, decreased sleep quality and quantity during childhood and adolescence are associated with decreased cognitive performance and inattentiveness (Beebe, 2012, for review). On the other side, in a meta-analysis that incorporates 86 studies and 35,936 school-aged children in total Astill et al. (2012) reported that although sleep duration was associated with executive functioning and performance in several cognitive domains, it was not related to sustained attention. However, Maski and Kothare (2013) suggest that various difficulties in interpreting the literature on attention and sleep arise from methodological constraints: most studies used subjective reports on neurobehavioural functioning and sleep variables that bias and decrease the cummulative effect size. Furthermore, in a review they claim that the influence of sleep on attention cannot be neglected. For instance sleep impacts areas of the developing brain that are crucial for attention, i.e., prefrontal lobe, striatum, and amygdala.

Very few studies have concentrated on the relation between sleep and attention in infancy and, as far as I know, no study has assessed both aspects using objective measures in this particular age group. One parent-report study on 105 infants found strong associations between brief attention spans and a more active sleep pattern in boys (Weissbluth & Liu, 1983). In another study with preschoolers, Lam, Mahone, Mason, and Scharf (2011b) found that children who slept less during the night made more impulsive errors on a computerised go/no-go task. Sleep problems in early childhood have been found to be an indicator for later attentional problems, too. O'Callaghan et al. (2010) for instance tracked 7223 children from birth to adolescence (14 years), assessing sleep as well as attention problems. Infants with sleep problems at 6 months were more likely to have attention problems at 5 years. The association between sleep during early childhood (2-4 years) and attention later in life (adolescence) was even higher. In a study by Gregory et al. (2008), parents rated their child's sleep (4-19 years old) with the Child Behaviour Checklist. Those children who early slept independently less had a higher probability of attentional problems later (18 - 32 years old). In summary, those studies indicate that sleep problems in infancy are an indicator for concurrent and often consistent attentional problems. However, it is not clear whether there is a causal effect or whether habitual sleep in healthy infants without sleep problems is also associated with attention.

Research on infants and children with sleep disordered breathing, which is associated with a more fragmented sleep pattern, found impaired cognitive performance (O'Brian et al., 2004; Bourke et al., 2011) as well as increased daytime sleepiness and hyperactivity (Melendres et al., 2004). Barnes et al. (2012) even showed that children with obstructive sleep apnoea had a significantly altered EEG in an oddball attention task and exhibited impaired neurocognitive performance compared to matched controls. Again, it is not clear whether there is a causal link between the sleep fragmentation and attention.

Finally, sleep problems have also been identified in children with ADHD. In general, children with ADHD have been found to be sleepier during the day, to have a more active sleep pattern, and also to be more often diagnosed with sleep apnea-hyponea (Cortese et al., 2006, for review). Furthermore, severe sleep problems in infancy have been associated with a later ADHD diagnosis (Thunstroem, 2002). However, the number of studies is still limited and challenged. For instance, Moldofsky (2001) assessed sleep variables in ADHD children and controls with actigraphy and parent report. Although parents of ADHD children rated their child's sleep as problematic, the more objective actigraphy data did not mirror this finding. The ADHD children in this study actually slept longer than the controls. The author suggests that the apparent sleep problems to which parents are sensitive may actually be caused by challenging behaviours around bedtime.

10.1.2 The operationalisation of visual attention: saccadic reaction time and the gap/overlap task

In this study I operationalised attention in terms of saccadic reaction times under different conditions using eye-tracking. Attention considerably affects saccadic eye movements in adults (Hutton, 2008, for review). For instance, when people look at an object, they often also attend to this object and saccades often co-occur with shifts of attention. For this reason, eye movements are often investigated when assessing the development of visual attention during infancy and childhood. The visual system, as well as the ability to make voluntary eye movements, develops from birth up until adolescence (Luna, Velanova, & Geier, 2008, for review). Moreover, this evolution goes hand in hand with the amelioration of cognitive control.

I introduced two measures of visual attention in this study: saccadic reaction time and the gap/overlap paradigm. Saccadic reaction time was simply determined by the time in milliseconds that infants needed to look from a central target on the screen to an object that appeared in the periphery of the screen. The central target in this case disappeared as soon as the peripheral target appeared. The gap/overlap task also assesses this saccadic reaction time under two more conditions. In the first condition, the central target disappears shortly before the peripheral one emerges – this is called the gap condition and facilitates saccadic movements. In the overlap condition, the peripheral target appears while the central target remains on the screen necessitating disengagement from the central stimulus. The gap/overlap task and its effects have been explored in a large number of studies so far on adults (Hutton, 2008) and infants (Hood & Atkinson, 1993a). In typical development at all ages the gap condition gives rise to faster saccades and the overlap condition to shorter saccades.

S. V. Wass and Smith (2014) reported correlations between cognitive control and the variability of fixation durations in 11-month-old infants who participated in a battery of eye-tracking tasks that lasted 90 minutes. Increased cognitive control was associated with decreased variability in fixation durations. These findings point in the same direction as results from Colombo, Mitchell, Coldren, and Freeseman (1991) who reported that infants with shorter fixation durations performed better on a perceptual-cognitive task. Importantly, S. V. Wass and Smith (2014) found associations between mean fixation durations and saccadic reaction times assessed with the gap/overlap task. This suggests that reaction times may be an indicator for other cognitive processes. Sacrey, Bryson, and Zwaigenbaum (2013) assessed reaction times longitudinally in infants from 6 to 36 months in an ecologically more valid play situation than the gap/overlap eye-tracking paradigm. Those infants who got a diagnosis for autism spectrum disorder at 36 months took longer to disengage from a stimulus at 12 months. Moreover, the increased reaction times stayed consistent at 15, 18 and 24 months of age.

In the gap/overlap paradigm, studies have generally found fastest reaction times in the gap condition and slowest in the overlap condition over the first year of life (e.g., Hood & Atkinson, 1993b) Furthermore, reaction times decrease with age (e.g., Matsuzawa & Shimojo, 1997; Frick, Colombo, & Saxon, 1999; McConnell & Bryson, 2005; Nakagawa & Sukigara, 2013). For instance, Hood and Atkinson reported significant decreases in latency between 1 and 3 to 4 months (Atkinson, Hood, Wattam-Bell, & Braddick, 1992; Hood & Atkinson, 1993b, 1993a). There is, however, little consistency in the literature on when the decrease in reaction time levels off. For example, Matsuzawa and Shimojo (1997) found significant decreases between 2.5 and 3.4 months, further decreases up until 6 months, and a levelling off between 6 and 12 months. On the other hand, Hicks and Richards (1998) reported that infant latencies levelled off between 10 and 16 weeks. Atkinson et al. (1992), who tested 1- to 3- month-old infants in the gap/overlap task using different variations, suggested that the maturation of the executive cortical orienting system underlies the developmental changes in reaction times. In fact Csibra, Tucker, and Johnson (1998) showed that the EEG in 6-month-old infants differed from the adult one when performing the gap/overlap task. Hunnius, Geuze, and van Geert (2006) as well as Butcher, Kalverboer, and Geuze (2000) could not find any individual stability in the disengagement latencies in a sample of 6- to 26-week-old infants who were tested longitudinally every 2 weeks. Nevertheless, on average the infants got quicker over developmental time. Infants made the fastest progress between week 9 and 16, but reaction times continued to decrease after that, too (Butcher et al., 2000). Another study found that the reaction times in the gap condition changed less compared to those in the overlap condition between 2.5 and 12 months (Matsuzawa & Shimojo, 1997).

This is interesting because longer latencies in the overlap condition in infancy are associated with poorer cognitive or emotional developmental outcomes. For instance, 3- to 4-month-old infants with longer fixation durations were slower in the overlap disengagement condition only (Frick et al., 1999) and had more variable saccadic latencies. In another study, infants were tested longitudinally in the gap/overlap task at 12, 18, 24, and 36 months (Nakagawa & Sukigara, 2013). Longer latencies in the overlap condition at 12 months were associated with concurrent low temperamental self-regulation. Surprisingly, at 18 and 24 months there was a positive correlation with effortful control. The authors cautiously explain this by a shift from the orienting to the executive network during this period of time. McConnell and Bryson (2005) employed the gap/overlap task in 2-, 4-, and 6-month-olds. Shorter disengagement latencies were associated with more smiling and less frustration in all age groups. Finally, atypical outcomes in the overlap condition have also been associated with autism in adults (e.g., Kawakubo et al., 2007) and during development (Elsabbagh et al., 2009). Kawakubo et al. (2007) reported abnomal electrophysiological brain activity in the overlap condition in autistic adults that was not correlated with their IQs. Elsabbagh et al. (2009) showed that 9-10-month-old siblings of children with autism were slower in the overlap and gap condition, suggesting that features of attention may be predictive of a subsequent autism diagnosis.

10.1.3 The present experiment

The aim of this study is to investigate the prospective link between infant sleep quality and subsequent visual attention performance i.e., reaction time and disengagement / facilitation. I employed eye tracking paradigms for measuring visual attention, and actigraphy to access developmentally-sensitive sleep parameters. I expected that higher-quality sleep (less sleep fragmentation and longer night sleep time) would be related to quicker reaction times and disengagement among infants at one point in time, after controlling for potential covariates such as family SES and prior visual attention abilities. In this context, I aimed to compare relations between attention and habitual sleep in the week before testing, as well as sleep assessed only the night before testing. Moreover, my goal was to investigate the extent to which habitual sleep early in infancy could be an indicator for later visual attention.

10.2 Methods

10.2.1 Participants

All of the 40 infants except one at 6 months and 2 at 8 and 10 months were tested on the gap/overlap task. However, data from several 4-month-old infants could not be included in the analysis because of problems that occurred during eye-tracking: for those infants the eye-tracker did not track the eye-movements continuously, which is crucial in this type of gaze-contingent paradigm. The exact number of infants included in the analyses for each task type is presented in Table 10.1.

10.2.2 Tasks and coding

Gap/overlap task All three conditions of the gap/overlap task started with an attention grabber (a colourful watch) at the centre of the screen that rapidly expanded and contracted in size in order to attract the infant's attention. The background colour of the screen was either pink or green. In the baseline condition, the watch disappeared when the infant looked at it for at least 0.5 seconds and simultaneously an animation emerged at either the right or left hand side of the screen (e.g., a cloud). Sides were chosen randomly. This peripheral target remained on screen for 3 seconds if the infant did not look at it. If the infant fixated it before that, a spinning animal was presented at its place together with a funny tone as a reward. In the gap condition, a blank screen was presented for a 200 milliseconds in between the presentation of the central and the peripheral stimulus. In the overlap condition, the peripheral target appeared while the central attractor continued to be displayed. The procedure of the gap/overlap task is illustrated in Figure 10.1. Saccadic reaction times were assessed in each condition by the time that infants took from looking at the central object to looking at the peripheral object.

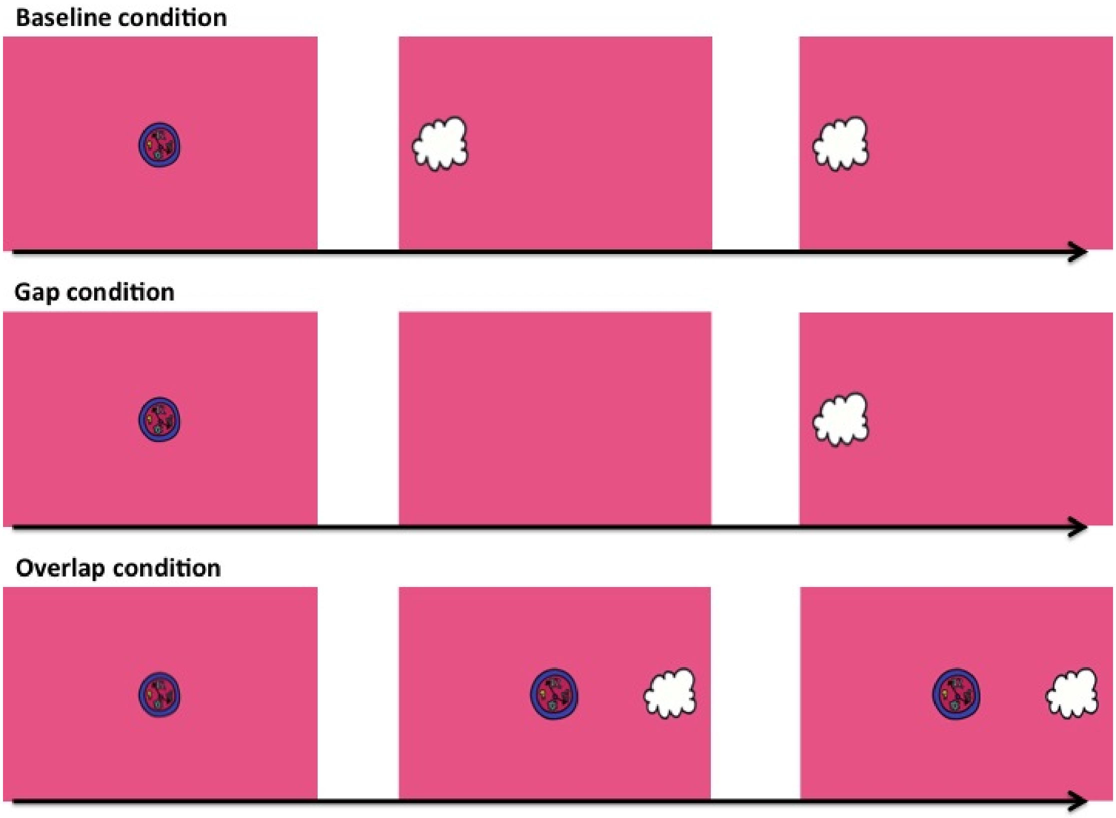


FIGURE 10.1: Illustration of the three conditions in the gap/overlap task.

Reaction time The reaction times were calculated on the basis of the first saccade at the beginning of the familiarisation and test trials in the memory and number tasks as well as of the saccadic reaction time in the baseline condition of the gap-overlap task.

Similar to the baseline condition in the gap/overlap task, each trial in the memory and number task was preceded by a central stimulus that was presented together with an attractive noise. The trial only started when infants fixated this stimulus. In both tasks, two targets were presented in each trial at each side of the screen. For the memory task, this was a frame with a moving toy and for the number task it was a big circle including a number of dots. Prior to the analyses, all trials in which no initial first look towards the central stimulus was recorded (due to equipment failure or because the infant was not attending) and all trials in which the infant did not directly look from the central to the peripheral target were excluded.

Saccadic reaction times in those tasks were assessed in a standardised way using a Matlab script. A saccadic eye movement only counted as success if it lasted at least 30 milliseconds. Moreover, all trials with reaction times less than 100ms and more than 1200ms were excluded as in Johnson and Posner (1991) and Elsabbagh et al. (2009). Infants with data from two or less valid trials were excluded from the analyses.

10.3 Data analysis and results

The analyses were conducted in two steps: first, I analysed the saccadic reaction time data extracted from the familiarisation paradigms employed in the study, and second, I focused on the gap-overlap task which was introduced in this chapter. At each step, I first concentrated on the reaction time data and their change over developmental time. Then, I addressed the prospective link between infant sleep quality and subsequent visual attention performance, while controlling for other covariates (e.g., socio-demographic variables).

10.3.1 Reaction time

Table 10.1 summarises the number of infants tested with the gap/overlap paradigm at all ages. Furthermore, the number of infants from whom data were included in the final analyses is reported for the gap/overlap, the memory, and the number task, i.e., the number of infants with valid trials. For those infants, the table also presents the mean number of valid trials in the gap/overlap task per condition.

Mean reaction times over the different tasks A 4 x 3 ANOVA with age (4, 6, 8, and 10 months) and task type (memory, number, and gap/overlap task) showed that reaction times differed significantly between ages, $F(1, 370) = 6.04$, $p < .001$, and between the tasks, $F(1, 370) = 692.61$, $p < .001$. Pairwise t-tests with bonferroni correction revealed that saccadic reaction times did not differ between ages (see Figure 10.2 for the distribution of the reaction times). Pairwise comparisons also showed that

TABLE 10.1: Mean number of infants tested and of failed trials as well as mean number and standard deviation of valid trials for all four ages.

		4 months	6 months	8 months	10 months
Number task					
Included infants		25	36	38	37
Memory task					
Included infants		18	29	31	33
Gap/overlap task					
Tested infants		40	39	38	38
Included infants	gap	19	37	37	36
	base	19	38	36	36
	overlap	15	34	35	36
Mean number of valid trials	gap	7.8 (4.6)	11.9 (4.0)	14.2 (5.1)	15.1 (4.8)
	base	6.8 (4.4)	10.9 (5.2)	13.6 (4.8)	12.7 (4.3)
	overlap	5.8 (4.9)	11.6 (5.0)	12.5 (5.7)	11.4 (5.1)

latencies differed between the three tasks: they were quickest in the baseline condition of gap/overlap task and slowest in the memory task (Figure 10.2).

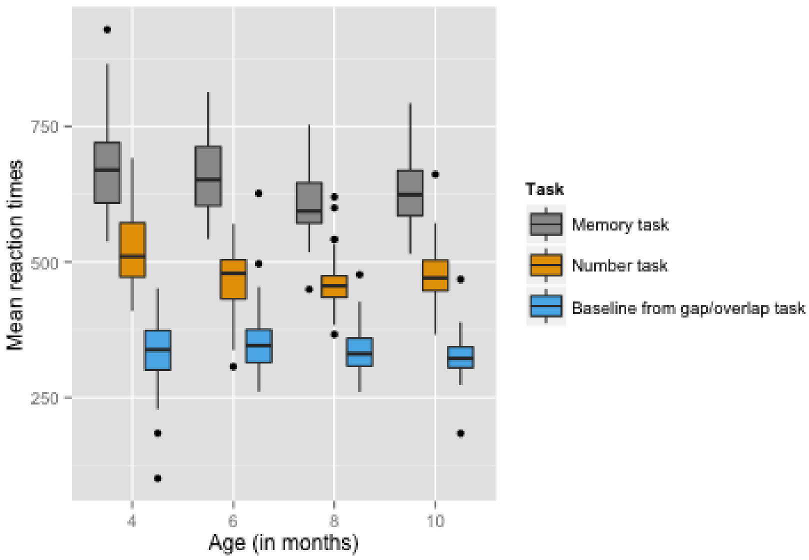


FIGURE 10.2: This figure shows mean saccadic reaction times for the first saccade in each test trial in different eye-tracking tasks at 4, 6, 8, and 10 months.

Correlations between tasks It was only in the younger infants that significant positive correlations between latencies emerged across the tasks (see Table 10.2).

Table 10.2: Correlations between the latencies in the three tasks per age group.

		Number task	Baseline of gap/overlap task
4 months	Memory task	.74**	.01
	Number task	-	.08
6 months	Memory task	.36*	.41*
	Number task	-	.33*
8 months	Memory task	-.05	.00
	Number task	-	.21
10 months	Memory task	.33+	.00
	Number task	-	-.09

Note. + $p < .1$, * $p < .05$, ** $p < .01$.

Possible covariates Partial correlations between the parental educational / number of siblings and saccadic reaction time, while controlling for age and task type, revealed no association between those variables (education: $r = .03$, $p = .971$; sibling: $r = .57$, $p = .569$).

10.3.1.1 Reaction time over developmental time

In order to investigate whether there was change over time in the saccadic latencies that differed between tasks, I set up a multilevel analysis with four models using R and the NLME package (Pinheiro et al., 2014). Outcome variable was the reaction time which was nested in the infant, age, and task type variable. The baseline model only included the intercept as predictor and age (4, 6, 8, and 10 months), task type (memory task, number task, gap/overlap task), as well as the interaction between age and task type were added one after another.

Age did not have a significant effect on reaction time, $\chi^2(3) = 2.32$, $p = .508$. But there was a main effect of task type, $\chi^2(2) = 599.57$, $p < .001$. The interaction between age and task was significant, too, $\chi^2(6) = 25.27$, $p < .001$. Planned contrasts revealed that reaction times were slowest in the memory task and differed significantly from those in the number task, $t(230) = -21.69$, $p < .001$, $r = .82$. They also differed significantly from saccadic latencies in the gap/overlap task, $t(230) = -41.32$, $p < .001$, $r = .94$. Furthermore, contrasts showed that between 4 and 6 months as well as between 6 and 8 months the reaction times in the gap/overlap condition decreased less than in the memory condition, 4 vs. 6 months: $t(230) = 3.00$, $p = .003$, $r = .19$, 6 vs. 8 months: $t(230) = 2.85$, $p = .005$, $r = .18$.

10.3.1.2 Relation between reaction time and sleep

A series of correlations were conducted in order to test whether reaction times in the memory and number task were related with the sleep measures. After adjusting the correlations for multiple tests none of them turned out to be significant. Table 10.3 presents the correlation coefficients.

Table 10.3: Concurrent and longitudinal correlations between the sleep variables and the reaction times in the number and memory task at 4, 6, 8, and 10 months.

		Memory task				Number task			
	months	4	6	8	10	4	6	8	10
TST	4	-.17	-.01	-.31	-.05	-.36	-.03	.02	-.10
	6	-	-.10	.10	.19	-	-.05	-.33	-.11
	8	-	-	.06	.01	-	-	-.01	-.02
	10	-	-	-	.16	-	-	-	-.17
EFF	4	-.38	-.29	-.26	-.09	-.24	-.05	-.15	-.16
	6	-	-.14	-.16	.23	-	.19	-.34	-.07
	8	-	-	-.13	-.04	-	-	-.20	-.19
	10	-	-	-	.10	-	-	-	.10
WASO	4	.38	.36	.29	.07	.13	.03	.20	.08
	6	-	.13	.18	-.20	-	-.22	-.32	.06
	8	-	-	.13	.02	-	-	.22	.17
	10	-	-	-	-.05	-	-	-	-.13
DAY	4	-.07	-.07	-.39	-.24	.08	-.19	-.03	-.09
	6	-	.13	-.10	-.14	-	-.05	-.34	-.02
	8	-	-	-.27	-.23	-	-	.34	-.12
	10	-	-	-	.06	-	-	-	-.05
LAT	4	.19	.02	-.36	.28	.21	-.03	-.12	.24
	6	-	-.07	.16	-.02	-	-.08	-.10	-.15
	8	-	-	-.14	.15	-	-	-.07	-.08
	10	-	-	-	.02	-	-	-	-.01
RO	4	-.04	.11	.15	.09	.08	.03	.12	.29
	6	-	-.08	-.21	.03	-	-.09	.30	.31
	8	-	-	-.15	-.21	-	-	.27	.02
	10	-	-	-	.16	-	-	-	-.13

Note. TST: total night sleep time, EFF: sleep efficiency, WASO: wake after sleep onset, DAY: day sleep duration, LAT: sleep onset latency, RO: regularity of sleep onset.

10.3.2 Disengagement and facilitation

As in Elsabbagh et al. (2009), I excluded all trials with reaction times less than 100ms and longer than 1200ms. Furthermore, I excluded all infants with less than 15 valid trials. The number of infants that met inclusion criteria is given in Table 10.1. In the analyses, I first examined whether the number of valid trials had any impact on the reaction times and present the descriptive statistics. Then, I investigated the extent to which latencies changed with age. Finally, I explored the relation between sleep and visual attention in the gap/overlap task.

10.3.2.1 Descriptive statistics

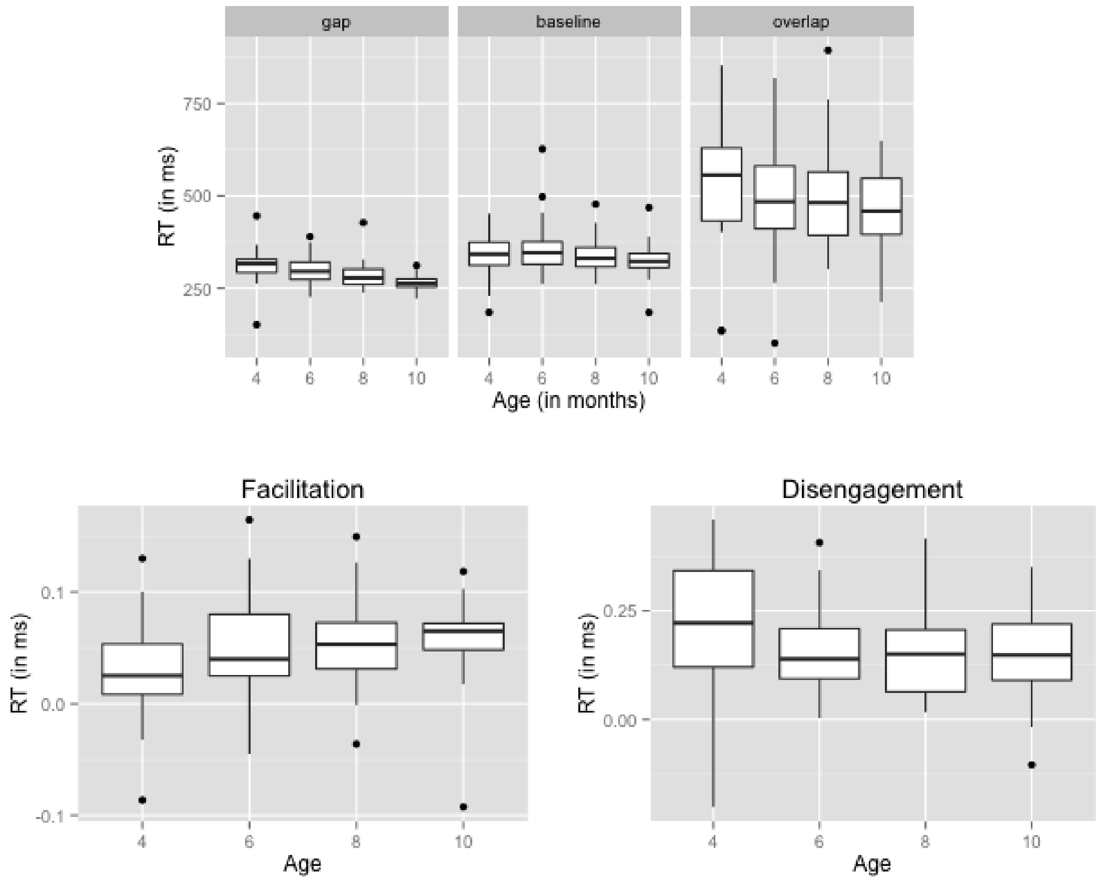
Number of valid trials per age group As can be seen in Table 10.1, 4-month-old infants completed less valid trials in all conditions of the gap/overlap task compared to the other age groups. This was mainly caused by difficulties I experienced with infants from this age group where the eye-tracker did not properly record the eye movement (possibly due to watery eyes) and where I therefore stopped testing after a few attempts. There were, for instance, 15 infants at 4 months with less than 10 trials in total but all infants in the other age groups did more than 10 trials. The minimum number of trials was 14 at 6 months, 20 at 8 months, and 14 at 10 months.

For the reason stated above, it is also difficult to compare the number of trials in which infants did not disengage properly over age and condition. In older ages (6, 8, and 10 months), the mean number of trials without disengagement was 2.68 (SD = 3.34), whereas at 4 months the mean number was only 1.94 (SD = 1.78), but this is likely due to the small number of valid trials.

In order to test whether there was a learning effect, I calculated a partial correlation between reaction times in each trial and the trial number (first, second, third etc.). Age (4, 6, 8, and 10 months) and condition (gap, baseline, overlap) were included as control variables. The trial number was not related to the reaction time, $r = -0.68$, $p = .502$.

Mean reaction times over conditions and the facilitation / disengagement effect Figure 10.3a presents means and standard deviations for the reaction times in the three conditions over the four age groups. With the reaction times obtained in the

(A) Saccadic reaction times in the gap, baseline, and overlap condition at 4, 6, 8, and 10 months.



(B) Facilitation effect (difference between reaction times in the gap and baseline condition of the gap-overlap task) at all ages.

(C) Disengagement effect (difference between reaction times in the overlap and baseline condition of the gap-overlap task) at all ages.

FIGURE 10.3: Reaction times, the facilitation, and the disengagement effect in the gap/overlap task at 4, 6, 8, and 10 months.

gap/overlap task, a disengagement and a facilitation effect can be calculated (see, for example, Elsabbagh et al., 2009). The disengagement effect is defined as the difference between the infant's mean reaction time in the overlap and the baseline condition, whereas the facilitation effect is defined as the difference between the gap and the baseline condition. Both effects are presented in Figure 10.3b and Figure 10.3c.

Correlations between conditions Table 10.4 presents the correlations of the mean reaction times between the three conditions of the gap/overlap task and with the number of valid trials (reaction times between 100 and 1200ms from infants with more than 15 trials). At 6 months, infants with fewer trials took longer to make a saccade in all conditions. Since there was no learning effect[1], this suggests that infants who completed more trials were quicker in their reaction time per se. There were significant correlations between conditions, in particular at 6 and 8 months. The missing correlations at 4 months could be explained by the small sample size remain at that age.

TABLE 10.4: Correlations between the conditions in the gap/overlap task and the number of valid trials per age group.

		Baseline	Overlap	Number of valid trials
4 months	Gap	-.01	-.27	-.07
	Baseline	-	-.07	.31
	Overlap	-	-	-.27
6 months	Gap	.64**	.63**	-.34*
	Baseline	-	.54**	-.33*
	Overlap	-	-	-.34*
8 months	Gap	.55**	.33*	-.01
	Baseline	-	.78**	-.20
	Overlap	-	-	-.27
10 months	Gap	.35*	-.04	.04
	Baseline	-	.16	-.11
	Overlap	-	-	-.08

Note. + $p < .1$, * $p < .05$, ** $p < .01$.

Possible covariates I conducted two partial correlations between the saccadic latencies in the gap/overlap task and parental educational background / binominal variable describing whether the infant had siblings, while controlling for age and condition. Reaction time was neither correlated with parental education, $r = -0.23$, $p = .816$, nor did it differ between infants with a sibling or without, .37, $p = .712$.

10.3.2.2 Disengagement / facilitation over developmental time

In order to investigate whether the facilitation and disengagement effects changed with age, I employed a multilevel analysis using R and the NLME package (Pinheiro et al., 2014). Four models were created with reaction time as the outcome variable. The three levels of the models (nested variables) were infant, age, and condition. I compared a baseline model including no predictors other than the intercept, with models where I

[1]To verify this, I repeated the partial correlation between the trial number and the reaction time controlling for the condition with the data from the 6-month-old infants only. The correlation was not significant, $r = -0.84$, $p = .408$.

added first age (4, 6, 8, 10 months), then condition (baseline vs. overlap), and finally the interaction of age and condition. Moreover, planned contrasts were defined in order to test whether the reaction times in the gap condition differed from those in the baseline condition (facilitation effect) and whether there were significant differences between latencies in the overlap and baseline conditions (disengagement effect).

Age had a significant main effect on reaction times, $\chi^2(3) = 8.22$, $p = .041$ and condition had a significant main effect, $\chi^2(2) = 345.93$, $p < .001$. The interaction between age and condition was marginally significant, $\chi^2(6) = 11.42$, $p = ..076$. Planned contrasts on the model including age revealed that the saccadic latencies overall decreased from one tested age to the next, 4 to 6 months: $t(88) = -3.64$, $p < .001$, $r = .36$, 6 to 8 months: $t(88) = -4.35$, $p < .001$, $r = .42$, and 8 to 10 months: $t(88) = -4.29$, $p < .001$, $r = .42$. With respect to the **facilitation effect**, the planned contrasts showed that reaction times overall were significantly quicker in the gap than in the overlap condition, $t(239) = -17.54$, $p < .001$, $r = .75$. However, there was no significant age x condition interaction when comparing the the latencies from the gap and the baseline condition. Regarding the **disengagement effect**, infants were overall significantly slower in the overlap condition compared to the baseline condition, too, $t(239) = -24.61$, $p < .001$, $r = .85$. In contrast to the facilitation effect, the interaction between age and condition was significant: latencies in the overlap condition decreased more than in the baseline condition from one tested age to the next, 4 to 6 months: $t(239) = 2.96$, $p = .003$, $r = .19$, 6 to 8 months: $t(239) = 2.19$, $p = .029$, $r = .14$, and 8 to 10 months: $t(239) = 2.12$, $p = .035$, $r = .14$.

To sum up, infants were quickest in the gap condition and slowest in the overlap condition. Latencies within conditions changed over time between consecutive ages. Finally, there was a change over time in the disengagement effect but not in the facilitation effect.

Intercorrelation across ages Individual stability of saccadic latencies for each condition from 4 to 10 months is presented in Table 10.5 (correlations adjusted for multiple tests). Reaction times were predominantly positively related between ages in older infants, i.e., 6, 8, or 10 months. Furthermore, RTs in the gap condition were significantly correlated and stable in infants between 6 and 10 months in the baseline and gap conditions.

TABLE 10.5: Stability of individual variations in RTs for each condition in the gap/overlap task at 4, 6, 8, and 10 months.

		6 months	8 months	10 months
Gap	4 months	-.12	.14	-.16
	6 months	-	.37*	.40*
	8 months	-	-	.30+
Baseline	4 months	.51*	-.30	-.01
	6 months	-	.34*	.12
	8 months	-	-	.32+
Overlap	4 months	.05	-.18	.54*
	6 months	-	.08	.16
	8 months	-	-	.18

Note. + $p < .1$, * $p < .05$, ** $p < .01$.

10.3.2.3 Relation between disengagement / facilitation and sleep

In order to explore whether any of the sleep variables (total night sleep time, sleep efficiency, wake after sleep onset, mean day sleep duration, sleep onset regularity, sleep onset latency) was related with the facilitation or disengagement effect either concurrent or longitudinally, a series of correlations was conducted. After adjusting p-values for multiple tests, none of the correlations were significant. Table 10.6 presents all correlations coefficients.

TABLE 10.6: Concurrent and longitudinal correlations between the sleep variables and the facilitation and disengagement effect at 4, 6, 8, and 10 months.

		Facilitation effect				Disengagement effect			
	months	4	6	8	10	4	6	8	10
TST	4	.04	-.24	.25	.09	.23	-.07	.01	-.04
	6	-	-.12	.01	.24	-	.10	-.03	.15
	8	-	-	.09	.14	-	-	.19	-.08
	10	-	-	-	.16	-	-	-	-.12
EFF	4	.00	-.17	.16	-.10	.35	.06	-.18	-.13
	6	-	-.07	-.12	-.15	-	.04	-.44	.06
	8	-	-	-.23	-.08	-	-	-.28	-.13
	10	-	-	-	.10	-	-	-	.16
WASO	4	-.06	.12	-.10	.14	-.39	-.11	.18	.03
	6	-	.07	.13	.21	-	-.05	.47	-.06
	8	-	-	.24	.11	-	-	.32	.11
	10	-	-	-	-.05	-	-	-	-.18
DAY	4	-.10	.10	-.43	.00	-.45	.01	-.17	-.08
	6	-	.11	-.39	.04	-	-.19	-.09	-.11
	8	-	-	-.28	.12	-	-	-.16	-.24
	10	-	-	-	.06	-	-	-	-.14
LAT	4	-.05	-.12	-.15	.04	-.06	-.04	-.27	-.10
	6	-	-.24	-.16	.11	-	.21	-.15	.15
	8	-	-	-.13	.01	-	-	-.33	-.19
	10	-	-	-	.02	-	-	-	-.21
RO	4	.05	-.02	.08	.20	-.43	.21	.09	.11
	6	-	-.16	-.28	.19	-	.35	-.24	-.04
	8	-	-	-.32	.23	-	-	-.29	-.20
	10	-	-	-	.16	-	-	-	-.14

Note. TST: total night sleep time, EFF: sleep efficiency, WASO: wake after sleep onset, DAY: day sleep duration, LAT: sleep onset latency, RO: regularity of sleep onset.

10.4 Discussion

Saccadic reaction times were tested in different conditions when the infants were 4, 6, 8, and 10 months. Although the latencies derived from eye movements in familiarisation paradigms did not change with age, there were strong age-related changes in the gap/overlap task: overall infants got quicker over time. Latencies were quickest in the gap condition and slowest in the overlap condition. The disengagement effect, i.e. the difference between overlap and baseline conditions, decreased significantly more over time than the facilitation effect, i.e., the difference between the gap and baseline conditions.

Individual stability was only found in the gap and baseline conditions but not for latencies in the overlap condition. Moreover, there was no correlation with the saccadic latency measures and the sleep variables.

I replicated the finding that reaction times were fastest in the gap condition and slowest in the overlap condition (e.g., Hood & Atkinson, 1993b). Also, latencies decreased with age, as found in various other studies that employed the gap/overlap task with infants (Matsuzawa & Shimojo, 1997; Hicks & Richards, 1998; Frick et al., 1999; McConnell & Bryson, 2005; Nakagawa & Sukigara, 2013).

It has been suggested that distinct oculo-motor pathways influence saccadic reaction time in the gap and overlap conditions (Johnson & Posner, 1991; Hood & Atkinson, 1993a). The first one is a quicker maturing pathway from the retina to the superior culliculus, which impacts on the gap reaction time. The second affects latencies in the disengagement condition and relies on higher cortical pathways such as the frontal eye fields and the parietal lobe. Very young infants often have "sticky fixations" and are not able to disengage in the overlap condition. But the frequency of successful trials increases over the first months of life (e.g., Butcher et al., 2000). Matsuzawa and Shimojo (1997) claimed that the decline of latencies in the overlap condition after about 10 weeks of age can be explained by mechanisms involved in the disengagement of eye gaze. They found that the decrease in the frequency of disengagement happened at the same time as the decline in latencies. Since latencies continue to decrease after that, this mechanism apparently continues to become increasingly efficient with time. I found individual stability in the gap and baseline conditions but not in the overlap condition, which replicated findings from Butcher et al. (2000). They tested infants between 6 and 26 weeks in the baseline and overlap conditions and could not find individual stability within this age group. This indicates that the mechanism is still developing over the first year of life.

None of the correlations between saccadic reaction time and any of the sleep variables was significant. Astill et al. (2012) did not find support for the association between sleep quality / quantity and attention in their meta-analysis of studies on children. They therefore discuss possible explanations. For instance, they suggest that in children the default mode network is not yet fully developed which leads to a different effect of sleep loss – for instance, hyperactivity instead of attention difficulties. Moreover, in this study, I focussed on reaction time, which is again a certain type of attention. It could be that only aspects of higher-level cognitive functioning relate to sleep in normal developing infants, which would exclude lower-level saccadic reaction time processes.

10.5 Summary

To sum up, I found different saccadic latencies in the three tasks that were investigated in this study. However, those did not change over time, were not related with plausible co-variates, i.e., number of siblings and parental education, and were not associated with the sleep variables. The gap/overlap task yielded much clearer findings. First of all, although there was no training effect within infants, those infants who did more trials were on average quicker in their reaction times. Latencies were quickest in the gap condition and slowest in the overlap condition. Over time, there was a general acceleration. However, the decrease in the disengagement effect was significantly stronger than the change in the facilitation effect, probably due to the fact that disengagement is a more difficult process, whereas facilitation was already in place earlier in development. I found individual stability in the baseline and gap conditions but not in the overlap condition, suggesting that factors influencing disengagement are still developing and changing at 10 months. Finally, surprisingly there were no significant correlations between the outcome in the gap/overlap task and the sleep variables.

Chapter 11

General Discussion

There is no period in life that requires a higher receptivity and readiness to learn than infancy. Optimal conditions in this stage are crucial for learning and achieving later developmental milestones without struggling. Therefore, scholars often try to investigate and to define those advantageous conditions. Surprisingly, sleep is a rather neglected topic in this context although early on human infants spend more time asleep than awake (Davis et al., 2004). We still don't know exactly what constitutes good quality sleep in infancy. Moreover, inter-individual variability in sleep variables during infancy is considerable (Galland et al., 2012). Yet it remains unclear as to whether these differences relate to concurrent or later variations in cognitive performance. Understanding these relationships better would be an important step towards developing and implementing effective interventions and training parents and caregivers.

The aim of my thesis was to investigate infant sleep variables over developmental time alongside several aspects of cognitive functioning in order to explore possible concurrent and longitudinal associations. In this context, I aimed to examine habitual sleep using an objective measure, i.e. actigraphy, in addition to the more often employed parental report.

In this chapter, the main findings of this longitudinal study are recapitulated and broken down into the specific cognitive measures and their association to habitual night sleep. An attempt is made to draw some broader conclusions from the research conducted in this thesis and to synthesise and combine some of the findings into a broader picture. Finally, a set of questions for future research are raised and some limitations of the current exploratory study are listed and explained. The final section leads to a personal reflection on the lessons learnt in the course of this PhD project.

11.1 Summary of findings

11.1.1 Sleep

Habitual sleep was assessed using actigraphy, sleep diaries, and sleep questionnaires. Data acquisition and extraction was explained in detail in Chapter 5. Since I only implemented actigraphy recordings during the night time – it is trickier during the day when infants are often carried around while sleeping – reports in the sleep questionnaire were consulted for the description of day-time sleep. Night sleep duration was defined as average time in bed, sleep period, and total sleep time, and unsurprisingly all three were strongly correlated. There were age-related differences in all the night sleep duration measures and in particular an increase between 4 and 6 months. This supports existing evidence that sleep variables stabilise quite early over the first year of life (Galland et al., 2012).

Regarding night sleep fragmentation, there was a considerable decrease over time in wake after sleep onset, night waking frequency, and sleep efficiency, which is consistent with previous findings (Galland et al., 2012). Again, the change was highest between 4 and 6 months of age, and all of those measures correlated with one another. Moreover, activity during night sleep dropped over time. Variables that did not change between 4 and 10 months were sleep onset latency as well as bedtime regularity in the evening. The few studies on developmental changes in sleep onset latency are summarised in a meta-analysis by Galland et al. (2012), which also found stability from early on in infancy. Unsurprisingly, the mean day-sleep duration decreased slightly over developmental time.

Interestingly, individual stability in night sleep duration emerged only in older infants, while sleep fragmentation was more stable in younger infants. This suggests that aspects relating to sleep fragmentation are likely to be more consistent in younger infants (e.g., night feeding is common in all infants at 4 months, whereas teething or illnesses occur only randomly but could affect sleep disruption in older infants).

Correlations between sleep variables from the actigraphy data and the questionnaire report data showed that parents were more accurate at estimating sleep duration than sleep fragmentation. In particular, in comparison with the actiwatch, parents did not pick up reliably on the awakenings of their child and underestimated the time spent awake. This is a crucial result because it highlights the importance of objective sleep measures in developmental studies.

In Chapter 6, I described the bedtime arrangements and routines that families adopted. No association was found between those aspects and habitual sleep. One explanation is that in the literature, sleep problems have been related with co-sleeping and with a lack of bedtime routine (Adair et al., 1991; Mindell, Telofski, et al., 2009; Sadeh et al., 2010). By contrast, the majority of participating parents in the current study did not consider their infant's sleep to be a problem. Consequently, the complexity and length of a bedtime routine could be deemed less important. Moreover, if infants co-slept, it was mostly in the parents' room but not in the parents' bed. Only the latter has been associated with poorer sleep quality (Mosko et al., 1997b).

11.1.2 Cognitive functioning

11.1.2.1 Memory

Short-term memory development was investigated using a paradigm from Richardson and Kirkham (2004) described in Chapter 8. Infants looked longer to the 'correct' side at 6 and 8 months, which indicated that they had made the visuo-auditory mapping and correctly remembered that a toy should appear at that location. However, there was no significant difference in looking time to the 'correct' and 'incorrect' sides in 4- and 10-month-old infants. It is plausible that at 4 months, infants are not yet able either to make the mapping or to remember it or to shift voluntarily their attention, but it is questionable that they loose this ability when they reach 10 months. So there must be another reason for the failure when the children are older. Interestingly, when investigating how infants changed looking patterns between two visits I found that those who already looked correctly at 4 or 6 months, changed their looking pattern and gazed more to the incorrect side when they were older. In other words, infants who clearly can make the mapping when older, look elsewhere when they do not immediately find the visual reward,, which suggests that shorter looking times in older infants does not mean that they fail to remember. The failure of infants at 4 and 10 months is thus likely to be due to different reasons, which I expand below.

The first explanation as to why 4-month-old infants failed to look more to the correct side is that they did not make the auditory-visual mapping. Either, this happened because they were not familiarised for long enough to be able to memorise the visual features and location of the stimuli and consequently did not map them to the auditory stimuli or because they were not able to map the visual and auditory features. The original study by Richardson and Kirkham (2004) on which this was based targeted 6-month-olds. Moreover, studies on visual attention in infancy have provided extensive evidence that visual scanning and information processing in very young infants is immature but develops over developmental time (Reynolds, 2015, for review). The exposure time that infants require to familiarise to a stimulus decreases over the first months of life when infants are increasingly able to focus their attention on relevant features of stimuli (Richards, 1997; Courage & Howe, 2004). Four-month-old infants in this study could have had not enough exposure time to remember both the object and its location. It is unlikely, however, that infants were able to remember the location of the object but failed to make the mapping. In a study of Brookes et al. (2001), 3-month-old infants were already able to learn associations of faces and voices and attended increasingly to a novel combination. Nevertheless, it could be more difficult for infants to learn a more arbitrary association between non-human sounds and objects.

The second explanation is that 4-month-old infants were not able to voluntarily shift their attention towards the correct side. This hypothesis is supported by studies showing that very young infants are able to reflexively shift their attention to an object, but have less control over their visual attention in the absence of objects, as was the case in this study (Posner & Petersen, 1990). However, the tracking data of this study indicates that infants did not just shift their attention to the incorrect side and stayed fixated there for the duration of the trial but that often infants shifted their attention between sides indeed.

Those two explanations can be embedded into the Posner's and Peterson's model of visual attention (Posner & Petersen, 1990). It argues that the posterior-orienting system develops up until month 6 and allows the infant to gain more control over visual processing. This system consists of two components. The first is an object recognition network, including both ventral and dorsal pathways from the primary visual cortex to the parietal and inferior temporal cortices. This component is crucial for object recognition and remembering of locations; it accounts for the first explanation offered above. The second component includes a spatial-orienting network in areas of the posterior parietal cortex, the superior colliculus, and the frontal eye fields. This component plays a role in disengaging and shifting attention and accounts for the second explanation.

The third explanation is that infants failed to encode and remember the correct side. This is very likely since infants short-term memory capacity increases over the first year of life (Ross-Sheehy et al., 2003; Ross-Sheehy & Newman, 2015). In a study on visual short-term memory, Ross-Sheehy et al. (2003) showed infants between 4 and 13 months two streams of 1 to 6 objects side by side where colours only changed on one side of the screen. The 4-month-old infants only looked longer the changing screen when there was one object whereas older infants preferred the changing screen when there were up to 4 objects. The same authors did a study on auditory short-term memory where 10-month-old infants were presented with sequences od tones that either stayed the same or changed over presentations (Ross-Sheehy & Newman, 2015). Infants at 10 months could only encode sequences of 2 tones but not 4. This suggests that 4-month-old infants in this study did not have enough short-term memory capacity in order to encode the sound together with the toy, which they were able to do when they were older.

11.1.2.2 Number processing

For the first time, small (2 vs. 3) and large (8 vs. 10/12/16) number processing was investigated longitudinally in the same infants. We replicated studies showing that already 4-month-old infants can differentiate small numbers (Carey, 2009; Piazza, 2010). Large number discrimination developed with age, as shown in previous research: at 6 but not at 4 months, infants were able to differentiate a 1:2 ratio; at 8 months, they succeeded on a 2:3 ratio, and at 10 months on a 4:5 ratio (Brannon, 2006; Cordes & Brannon, 2008; Libertus & Brannon, 2009; Piazza, 2010, for review). However, our study made it possible to examine the relationship between the two systems, since the data came from the same infants.

There has been debate on how the small and large number systems emerge and differentiate over time and whether they exclusively represent small or large numbers. In the thesis, I reviewed the current discussion on the topic. Many scholars believe that number processing is grounded on two distinct, innately-specified systems. However, several findings from the longitudinal study of my PhD project point towards a different explanation. First of all, only large number discrimination was stable between 8 and 10 months, indicating the there is still change over time before that age. Secondly, and importantly, correlations between small and large number discrimination were significant at 4 months, but not in the older age groups. This could suggest that both systems are initially linked together and become differentiated over the first months of life. Finally, I also investigated how number discrimination related to looking patterns during the task by exploring first saccades during a test trial as well as the area that was scanned and the fixation duration. The first saccade was closely linked to the ability to discriminate numbers and the scanned area was related with the first look. This might mean that participants could see both displays simultaneously before making their first saccade. Taken together these findings indicate that small and large number processing are both biased by features of visual exploration during their development and only progressively become individually specialised over the first months of life.

In general, I found that infants being presented with two different numbers during test trials look more in total towards the larger number irrespective whether this was a new or old one (e.g., they looked overall longer to 16 when being familiarised with 16 and tested with 8). More specifically, looking time differences between the old and the new number were generally only significant when infants had been familiarised with the smaller number and not with the larger number. This was surprising, because other studies such as the one from Xu and Spelke (2000) reported a novelty effect for either direction, whether from small to large or large to small. The mismatch between this study and some of the other existing literature can be explained by the different paradigms that were used. Most studies investigating numerical sensitivity in infancy employ a habituation paradigm, whereby infants are presented with one numerosity until they show signs of habituation, i.e., decreased looking time to the stimulus. Then they are shown presentations of a new and the old numerosity alternately in <u>different</u> trials. In general, looking times increase in trials with the presentation of the new numerosity but stay low for trials with the old one, which demonstrates that infants dishabituated and differentiated the number sets. This study used a preferential looking paradigm, whereby infants were presented with pairs of numerosities; they were first familiarised to one numerosity that was presented on the screen in two adjacent circles. During test trials, they were shown the old numerosity and the new one, with the new numerosity being presented on alternating sides. This means that the measure employed was not increase in looking time within one trial as in the habituation paradigm, but increase in looking time to one side. If infants reacted similarly in the preferential looking paradigm as in the habituation paradigm, they should look longer to the new side and not longer to the larger one as they did in this study.

Presumably, this result is due to two confounding effects. First, there is the habituation-dishabituation effect described earlier, i.e., that infants have the tendency to shift their attention to a novel object after increasing exposure to an old object (e.g., Sirois & Mareschal, 2002; Colombo & Mitchell, 2008). The other effect is that when infants get older, they show less looking time to basic objects but display longer looking times to more complex objects (Courage, Reynolds, & Richards, 2006). I will call this the complexity effect. That suggests that in this study, infants were more drawn towards the new number because of the habituation-dishabituation effect, but at the same time showed increased interest in the more complex set, i.e., the larger number. When infants had been familiarised with the smaller number in this study, both effects pointed in the same direction: infants looked longer to the new, and in this case, larger number because of both the habituation-dishabituation and the complexity effect. However, in the conditions where they had been familiarised with the larger and tested with the smaller number, the habituation-dishabituation effect pointed in the opposite direction from the complexity effect, i.e., the former directed the infants' attention towards the new and smaller number whereas the complexity effect made infants look longer towards the old and larger number.

The question is: could infants in this study differentiate the numbers or were they merely looking longer to the more complex set? Before explaining why I still think that infants were able to differentiate the numbers, I want to recapitulate how the stimuli looked like. The stimuli were produced with a program developed by Piazza et al. (2004), which has hitherto been employed by a large number of research groups and which controls carefully for continuous variables that change alongside number, e.g., total occupied area and luminance. This allowed area and luminance to vary greatly between sets during familiarisation, and some sets had the same parameters as the sets with the new number that were used in the test trials. Hence, infants were only familiarised to the number, and not to the total occupied area or luminance. Therefore, they might have shown longer looking times because of a change in number and no other variable. But could it be that they were still more interested in the more complex set? If infants were merely looking towards the side with 'more stuff' without detecting the change in number, they should have looked equally long towards the large number in test trials where they had been familiarised with the larger number as in test trials where they had been familiarised with the smaller number. In other words, they should have looked longer at 16 when being familiarised with 8 and when being familiarised with 16. However, in general, looking times to the old and new number were not significantly different when they had been familiarised with the larger number. This means that they looked for instance significantly longer to the new number 16 when they had been familiarised with the smaller number 8, but showed no preference for 8 or 16 when they had been familiarised with the larger number 16. This demonstrates that infants displayed a habituation-dishabituation effect.

11.1.2.3 Attention

Attention was assessed in terms of saccadic reaction time during different eye-tracking paradigms as well as specifically with the gap-overlap paradigm described in Chapter 10. There are different types of attention such as attention shifting, sustained attention or vigilance, and selective attention. The gap-overlap tasks as well as the saccadic reaction times in the eye-tracking tasks measure attention shifting, i.e., the ability and readiness to disengage from a central stimulus to a peripheral one in different conditions with different levels of difficulty. It was not possible to incorporate other measures of attention into the study for several reasons. First, it is very challenging to find or develop paradigms in very young infants in order to measure attentional abilities. On top of that, paradigms were needed that could be applied to infants of different age groups. Second, the duration of the test protocol was too long to allow to incorporate additional tasks. In particular it would have been interesting to assess vigilance or sustained attention because this was the type of attention mostly linked to sleep variables in previous studies.

Saccadic reaction times differed between tasks, i.e., they were slower in the memory task than in the number task. This could be due to the fact that in the number task infants' attention is directly drawn to one of the big circles on the screen whereas in the memory task, there is no visual stimulus and they have to shift their attention voluntarily from side to side.

In the gap-overlap paradigm, there were differences between conditions: latencies were shortest in the gap condition and longest in the overlap condition at all ages, as expected (Hood & Atkinson, 1993a). Moreover, saccadic latencies decreased with age. More specifically, while infants got generally somewhat quicker in the gap and baseline conditions, the change in the overlap condition was greater, which resulted in a decrease of the disengagement effect. These findings replicated previous studies (Matsuzawa & Shimojo, 1997; Hicks & Richards, 1998; Frick et al., 1999; McConnell & Bryson, 2005; Nakagawa & Sukigara, 2013). The acceleration of disengagement latencies throughout infancy has been explained by the maturation of underlying brain structures or pathways (e.g., Johnson & Posner, 1991; Atkinson et al., 1992; Hood & Atkinson, 1993a). Whereas infants show 'obligatory attention' in the first months of life (Stechler & Latz, 1966), i.e., they display 'sticky fixations' towards an object, with orienting behaviour beginning to appear in month 2 or 3 (Aslin, 1981). Between month 3 and 6 the posterior attention system matures further, which results in better attention shifting abilities and shorter latencies (Posner & Petersen, 1990; Johnson & Posner, 1991). To explain the different developmental trajectories in latencies in the gap and in the overlap condition, Fischer (1986) as well as Hood and Atkinson (1993a) suggested two processes of disengagement on the basis of Schiller's neuroanatomical model (Schiller, 1985) that rely on different pathways in the brain. Latencies in the gap condition rely on the retino-collicular pathway, which is relatively mature by 4 months. Latencies in the overlap condition are, however, based on extrastriate cortical areas that continue to develop over the 1st year and therefore still change over developmental time.

11.1.2.4 Questionnaire

Although the overall score in the Ages & Stages questionnaire was not stable over developmental time, the same infants were consistently coded as slightly below or close to the cutoff, an indicator for lower levels compared to their peers (see Chapter 7).

11.1.3 The association between sleep and cognitive functionning

Concurrent and longitudinal associations between sleep variables and attention, memory, and numerical sensitivity were explored. In summary, there were no associations between any of the sleep variables with attention. However, infants with less fragmented and more efficient sleep were better at number discrimination – an effect which was even more prominent for large numbers. Analyses of short-term memory showed the same association: very young infants whose sleep was less fragmented and more efficient performed better on the memory task. Although there were no longitudinal relations between sleep and number processing, this was the case for memory: I found that not only more efficient/less fragmented sleep but also longer duration were related to later short-term memory.

Sleep and attention There are several hypotheses as to why sleep variables were not related to **attention** in this study. First, this finding seems to contradict research on adults, which showed that shorter sleep durations (Neylan et al., 2010; Gumenyuk et al., 2011) and greater sleep fragmentation (Martin et al., 1996) were associated with poorer performance on psychomotor vigilance tasks. However, those tasks require different types of attention, i.e., longer attention spans and hence higher sustained attention, more working memory capacity, and higher activity levels, rather than simply disengagement of visual attention, i.e., attention shifting, as in the gap-overlap task. Basic reaction times in well-rested infants might accordingly not be affected by differences in habitual sleep, whereas sleep might impact on working memory and hence on the more demanding psychomotor vigilance tasks in adults. Therefore, it would be interesting to investigate the relation of infant sleep with other aspects of attention such as vigilance of selective attention. The relation between sleep and attention is thought to be caused by sleep effects on the functional integrity of the fronto-parietal network in the brain. When sleep deprived, individuals' ability to maintain attention for a longer period of time is reduced. Hence, sleep variables in infancy, such as sleep fragmentation, could have an effect on the ability to sustain attention for longer periods of time but not on reaction times – in particular not if infants are generally well rested as in this study. An example of interesting attention tasks that assesses different aspects of attention and would therefore be interesting to look at in the context of sleep effects is the gaze-contingent eye-tracking paradigm from S. Wass, Porayska-Pomsta, and Johnson (2011). In this task infants are visually rewarded whenever they focus on specific features displayed on the screen (e.g., a moving butterfly). In this example, the frame freezes as soon as the infant looks away from the butterfly and moves again as soon as the infant's gaze returns to the butterfly. In addition, increasing distractions are progressively added to the display, such as a tree or a sun. Infants' attention abilities are measured in terms of how quickly they discover the gaze contingency and how long they keep focused on the relevant feature. That means that sustained attention as well as working memory is assessed.

Secondly, research on adults has found that sleep deprivation was related to decreased attention (e.g., Van Dongen & Dinges, 2005; Banks & Dinges, 2007; Lim & Dinges, 2008, 2010). Note, however, that the infants participating in the current study were neither sleep deprived nor showed signs of sleepiness during testing. This would lead to the conclusion that attention is only affected by restricted sleep. Finally, in studies on children, the link between attention and sleep was most notably evident when investigating atypically developing infants (e.g., Melendres et al., 2004; O'Brian et al., 2004; Moldofsky, 2001) or infants already presenting with sleep problems (e.g., Gregory et al., 2008; O'Callaghan et al., 2010). Subtle sleep differences in typically developing infants without sleep problems may not impact on attentional abilities, even if sustained attention would have been assessed.

Sleep and memory In contrast to the gap-overlap task, **short-term memory** was related to sleep: it improved with more efficient and less fragmented sleep. This points in a similar direction as a study by Lukowski and Milojevich (2013), where habitual sleep was found to be related to imitation abilities in 10-month-old infants. The relation between sleep and memory variables in the current study could be explained in two ways. On the one hand, it is plausible that infants with better cognitive functioning are also generally more developed, which is paralleled by their sleep variables. This point is actually an issue affecting all other cognitive measures in this project, too, and that needs to be addressed by further research. It is so far very challenging to disentangle maturational from sleep effects and I will dwell on this question further later-on. Some studies have tried to assess the maturation of infants and indicate that sleep might serve as a developmental indicator of risk as. For instance, shown in a study on newborn babies by Minard, Freudigman, and Thoman (1999). In their study, sleep cyclicity in newborns was related to birth weight and to later mental development.

Also, sleep-wake state organization, for instance, serves as a measure of neurological integrity (Becker & Thoman, 1981; Beckwith & Parmelee, 1986). Sleep is also crucial for brain development, plasticity (Walker & Stickgold, 2006; Stickgold & Walker, 2007) and cognitive functioning, particularly in the first year of life (Ednick et al., 2009).

On the other hand, sleep might impact memory during development. As described with the Hippocampal-Neocortial Dialogue Model described in Chapter 2.1.2, new experiences are first stored in the hippocampus. During sleep, they are first reactivated and then transferred to and integrated in the neocortex. This process, i.e., sleep-dependent memory consolidation obviously describes the imprinting and storing of memories during sleep. In this study, however, short-term memory was assessed that did not include a process of sleep-dependent memory consolidation. One possibility is therefore, that quality sleep enhances the general ability of the brain to store and memorise events and consequently is related to better memory performance during the day. Another possibility relates to the first point. Sleep could enhance cognitive functionning in general and as a result also impact on memory. Probably, a combination of all aspects described play a role.

In the current study, sleep fragmentation turned out to be the variable most related to memory performance. Potentially, infants with more fragmented sleep get less non-active sleep, which is the equivalent of adult slow-wave sleep. Memory is especially affected by slow-wave sleep (Diekelmann et al., 2009). In the Hippocampal-Neocortial Dialogue Model, sleep spindles which characterise the integration of new memories into the neocortex occur during slow-wave sleep. Consequently, non-active sleep could be especially important for memory development during infancy and childhood (Huber & Born, 2014).

Differences between sleep and memory with respect to their relation with sleep I would like to recapitulate a bit more on the question, why memory and attention were differently related to sleep variables in this study. As already outlined, researchers assume that disengagement in the gap-overlap task relies on the posterior attention system described in the model by Posner and Petersen (1990), more precisely ventral and dorsal pathways from the primary visual cortex to the parietal and inferior temporal cortices, the superior colliculus, and the frontal eye fields. Those areas become relatively mature during the first months of life and only develop somewhat further after month

6. The memory task, however, requires several processes that are more complex than those required in the gap-overlap task, e.g., encoding of auditory and visual features, visual-auditory mapping, and controlled shifting towards one of the sides. For instance, infants shift their attention rather reflexively towards the peripheral stimulus in the gap-overlap task. In the test trials of the memory task, infants only hear the sound and have to shift their attention without a visual anchor. Therefore, it is plausible that, although the foetus already shows recognition memory (Hepper, 1996), cognitive processes such as the auditory-visual mapping and the voluntary shift of attention rely on brain processes that only mature later in development and are thus more sensitive to concurrent sleep variables.

Sleep and number processing Many scholars claim that cognitive domains, such as number processing, are innate because core representations of number are present throughout species, cultures, and over development (Kinzler & Spelke, 2007). Spelke (1994) suggested that infants have an initial knowledge of numbers, which is not learnt. This would imply that number processing would be relatively unaffected by sleep because, being innately-specified knowledge, it does not improve with better sleep. However, research showed that there are individual differences in numerical sensitivity in typically developing infants (Libertus & Brannon, 2010). Findings from the current study suggest that such differences relate to sleep or that number processing and sleep both relate to other developmental factors. Also, the results reported in Chapter 9 imply that the small and large number processing systems are not clearly distinct as often suggested by researchers (Hyde, 2011) and that early in life they relate to aspects of visual exploration (Karmiloff-Smith et al., 2012). Therefore, they may be more connected to sleep and factors impacted by sleep. Furthermore, the number task employed in this study might require processes that are related to sleep such as encoding during familiarisation.

Conclusion In summary, Sleep was not related to attention shifting abilities. However, it still needs more research in order to investigate associations between sleep variables and other types of attention, such as sustained attention. Sleep variables were furthermore related to short-term memory and number processing, which highlights the importance of sleep for different forms and levels of cognitive performance. However, due to the correlational design of this project, it is not possible to disentangle whether the same mechanisms underlies those two mechanisms or whether sleep is associated to the two distinct cognitive tasks. Since the number processing and the short-term memory task are both designed in a similar way – they rely on familiarisation – it is possible that similar cognitive processes are crucial for both tasks. Consequently, it is also possible that not pure number processing or pure short-term memory is related to sleep, but that there is another factor which relates to all aspects. I will dwell a bit more on this issue later-on.

11.2 Synthesis

The overarching aim of this thesis was to explore the association between cognition and sleep in infancy. It is the first longitudinal and cross-sectional study investigating the association between infant sleep and cognition with objective measures. In the following section, I address the main research questions of this project that were outlined in Chapter 1.

1. Are some sleep variables more related to cognition than others? Can we define more precisely what counts as high quality sleep in infancy? Generally, sleep fragmentation (i.e., wake after sleep onset and sleep efficiency) were more related to cognitive performance than sleep duration (i.e., total night sleep time, day sleep duration). Many other studies relied on parent report or were done with special populations such as preterms or atypically developing infants. However, there exists one other study on typically developing infants without sleep problems which also reports an association between sleep fragmentation measured by actigraphy and cognitive functioning, i.e., scores on the Bayley scales (Scher, 2005). Higher quality sleep in typically developing infants might therefore be defined in terms of fragmentation levels and not by sleep duration.

But why was sleep fragmentation more related to cognitive performance than sleep duration? First, sleep fragmentation could be particularly important because it serves as an indicator for better sleep-wake regulation and consequently for a higher neurological integrity (Becker & Thoman, 1981; Beckwith & Parmelee, 1986). In other words, it could serve as a measure of the maturational status of a child. Secondly, infants with less sleep fragmentation could spend more time in the non-active sleep phase, which is the counterpart of the adult slow-wave sleep. This phase could be particularly important for certain cognitive processes (Huber & Born, 2014). Sleep duration, however, was probably a less important variable for the infants in the current study because they were not sleep deprived and were generally well rested. Finally, there are individual differences in sleep duration that adults need for optimal cognitive functioning. This is likely also to be the case in infants.

2. Are there only concurrent or also longitudinal associations between sleep and cognition? In this study, there were concurrent as well as longitudinal correlations between sleep and memory, which replicates former findings of longitudinal associations between cognition and sleep during development (Gómez et al., 2011, for review). Interestingly, sleep duration and fragmentation were longitudinally related to short-term memory, although there were no concurrent correlations with sleep duration. This indicates that the association between sleep and cognition is complex. For instance, short sleep durations might not have any short-term consequences but could have a long-term impact. Also, longer sleep durations could increase brain plasticity at a given point in time (Walker & Stickgold, 2006; Stickgold & Walker, 2007), which might have an impact on cognitive functioning longitudinally.

3. Is there a time during the first year of life when the relation between sleep and cognition is stronger? The final research question is more difficult to answer from the current findings. It is, for instance, difficult to say whether sleep and short-term memory are related in older infants because performance in the particular memory task employed in this study was not linear. Consequently, in older infants longer looking times did not imply better short-term memory. But, since there were associations between sleep and number processing regardless of age, we can assume that there are correlations between sleep variables and cognitive performance in older infants, too. Moreover, there was some evidence that habitual sleep is related to problem solving/gross motor control in older infants (see Chapter 7 on Ages & Stages questionnaire). Nevertheless, it is not possible to conclude whether this relation is stronger or weaker at any particular age, and more research is thus needed. However, bearing in mind the large body of literature on the importance of sleep for cognitive functioning in adults (e.g., Walker, 2009), it is safe to conclude that there is probably no stage in life where sleep can be neglected.

11.3 Questions for future research

There remains a high need for investigating further the effects of infant sleep further. Given that sleep affects and is affected by so many different aspects of life (social, cognitive, emotional, physiological) the number of conceivable, interesting, and important studies is large. Let us therefore focus on a few research questions that I deem challenging and important to explore.

1. **The complexity of the topic.** As I have described throughout the thesis, the link between sleep and cognition, social functioning, as well as physiological processes, is bi-directional and highly complex. Likewise, sleep variables of infants also depend on other factors related to their developmental status. Consequently, it is very difficult to disentangle sleep effects from other factors. Future research that explores the link between sleep and cognition in infancy should therefore find ways to determine as many additional intervening factors as possible (e.g., maturational status, socio-economic background, quality of parent-child interaction, etc.) in order to draw the right conclusions.

2. **What about sleep EEG?** When analysing the data from this study, a question arose to whether infants with less fragmented sleep show different EEG patterns compared to those who wake up more often. Probably, the proportion of active versus non-active sleep is very different in both groups. If so, sleep fragmentation may just be a symptom in some infants whose sleep is more generally different. In that case, our aim should not focus solely on minimising disturbances in the bedroom in order to avoid sleep fragmentation, but particularly on understanding why those infants' sleep is different.

3. **Is waking up still necessary?** There is evidence that sleep fragmentation related to sleep problems is generally associated with decreased cognitive performance and social functioning (e.g., also induced by daytime sleepiness in the infant and parent) and should be avoided. However, does it have positive effects, too, that should

be considered in the light of interventions aimed at minimising sleep fragmentation? Although merely an anecdote, interesting to note is the fact that the two infants who woke up much more often than all the others in my study sample had very responsive, calm, friendly, and well-educated mothers. Those infants were in the normal range on the cognitive tasks. Consequently, it is possible that sleeping through is less relevant for some infants with a very fortunate background, and thus that the effects of sleep fragmentation differ as a function of the child's environment. This is speculative, but it goes into the same direction as ideas from researchers such as Willem E. Frankenhuis at the University of Nijmegen who found initially improved performance on some tasks in children raised in a harsh environment (Frankenhuis & de Weerth, 2013; Rickard, Frankenhuis, & Nettle, 2014, and unpublished data). He argues that this improved performance is a sign of adaptation to the harsh environment and not of a generally advanced development. Similarly, sleep duration and fragmentation could be less relevant factors for development for infants growing up in a very safe, responsive, and educated environment.

With respect to intervention, this would mean that we should not aim to completely avoid awakenings, i.e., sleep fragmentation. For example, some parents feed formula in the evening in order to prevent their infant from waking up too often. Or some parents swaddle their babies (wrapping infants in cloth in order to suppress movement) because this calms the infants and minimises awakenings. To better know the risks of different techniques, the aspects that support optimal development, and long-term consequences of distinct sleep variables is crucial when training parents and caregivers.

4. **Effects of habitual sleep versus learning during sleep.** This thesis has focused on the correlation between sleep variables and cognitive performance, which is different from the role of sleep in the direct consolidation of specific memories. The latter has been addressed in studies from the Rebecca Gomez lab at the University of Arizona which measure whether a nap improves the learning of the statistical regularities of an artificial language. However, those studies were done on at least 15-month-olds infants and more research on younger infants should focus on both aspects of sleep.

5. **Maturation versus sleep effects.** Generally, correlational studies as the one at hand have difficulties with disentangling sleep effect and maturation effects because

infants' sleep as well as cognitive variables may vary depending on maturation. The question is whether it is possible to investigate sleep effects and control for maturation in a longitudinal design. In principal, future studies with a similar design should carefully assess as many indicators of the maturational status of an infant as possible in order to be able and control for those aspects. Indicators for maturation could be physical variables such as height, weight, circumference, and muscle tone (Allen, 2005; Ballard, Novak, & Driver, 1979). Amiel-Tison, Allen, Lebrun, and Rogowski (2002) developed a method to describe neurological maturity from observations of the changes in neck, trunk, and extremity flexor tone and posture with gestational age.

11.4 Limitations

11.4.1 Other important sleep variables

As pointed out several times in the course of this thesis, I implemented the actigraph data collection during night-time, but not during the day. One reason was that asking parents to attach it to their child's ankle for a whole week, day and night, seemed rather a burden. Another reason was that I considered it difficult to use the day measures since often infants are asleep during the day while being rocked, laying in a push-chair, or in a car where external movement would have been recorded, too. Nevertheless, I realised some weeks after starting the study that having more data on daytime naps would have added valuable information, e.g., the proportion of day versus night sleep as well as the duration and regularity of the naps. Therefore, I subsequently started asking parents to write down daytime napping, too. Of course, more information about daytime sleep would have been advantageous.

11.4.2 Limitations of the eye-tracking measures

Choice of the attention measure As already pointed out at several points throughout the thesis, attention was assessed as saccadic reaction times under different conditions. This, however, only accounts for one type of attention, i.e., attention shifting or disengagement. It is more probable that sleep variables are related to other types of attention such as vigilance. Since sustained attention is affected by sleep disturbances and sleep deprivation in adults, it is also more likely to be related to sleep fragmentation in infants. Therefore, future research should rather include measures of more advanced types of attention such as sustained attention or working memory. One possible task that tests those aspects was already pointed out earlier (see S. Wass et al., 2011). Another possibility is to assess how long infants are able to focus when the employed testing procedure is relatively long. For instance, it would be possible to test how many minutes of eye-tracking tasks an infant would participate in before getting fuzzy. One additional aspect that has been assessed during this project is parent-child-interaction. Attention during parent-child interaction could be coded by investigating how long infants focus on certain toys, how attentive they react when their caregiver plays with them, or how many signs of activity, i.e., verbalisations, gestures etc., they show. In this thesis, I did not code those aspects but will do so in the future in order to extract other aspects of attention.

Choice of the short-term memory measure The short-term memory measures employed in this study demanded from infants not only to memorise a location, but also to do auditory-visual mapping. Moreover, the performance of this task could be measured only during test trials as a yes/no response: either infants looked longer to the correct side or they did not. Both aspects could be avoided by employing a normal visual preference paradigm. By, for instance, presenting infants with streams of two faces – one changing and one not changing face – we would expect them to get familiarised to the non-changing face over trials and look more to the changing face. With such a paradigm, infants would not need to do visual-auditory mapping. Moreover, it would be possible to extract a more continuous response, e.g., the number of trials until infants looked more than 55% of the time to the changing face.

Choice of the number processing measure As previously described, former studies on numerical sensitivity mainly used habituation paradigms whereas I employed a preferential looking paradigm. It might have been better to use an established and replicated task instead of creating a new one. But, since I wanted to test infants for more than one number condition, i.e., small and large numbers as well as familiarisation with the smaller and larger number, employing a habituation paradigm was not feasible. As reported in Chapter 4, I had aimed to design a habituation paradigm that would be interesting enough for the infants so as to hold their attention across multiple trials. However, habituation paradigms per se only function by boring infants; thus, conducting more than one run is impossible most of the time. The other possibility would have been to employ the change detection paradigm designed by Libertus and Brannon (2010). To test numerical sensitivity Libertus and Brannon (2010) showed infants streams of numbers on two screens with changing numerosities only on one of the two screens. Longer looking times to the screen with the changing numerosities demonstrate that infants are able to detect the number change. There were several reasons why we did not choose this paradigm (apart from the fact that Libertus and Brannon (2010)'s paradigm was relatively new when I started my PhD and the task had not yet been established for age groups in which we were interested). Firstly, it would still have taken too long to be able and test other aspects of cognitive functioning during the same visit. Secondly, it does not allow for the investigation of tracking patterns which were important in our study because we wanted to explore in greater detail similarities/differences between small and large number processing. Thirdly, it would have required a different set-up than the other cognitive tasks and consequently changes between set-ups during the testing procedure. However, since visits were already long, in particular for the 4-month-olds, we decided that this was not feasible.

11.5 Lessons learned

As I emphasised at several points in this thesis, I believe that sleep is a relatively neglected topic in developmental research, yet an enormously important one. For this reason, I never tired of the topic (pun intended!). However, during the PhD, there were times when I struggled with aspects of the project.

In particular, I wanted to include as many different aspects of development as possible to get a broader picture. Yet I had not foreseen at the beginning of my PhD that greater breadth obviously makes analyses more complex – not to mention that this approach required me to become expert in multiple methods (i.e., eye-tracking, programming, actigraphy etc.). I realised with time that infant development is not simply linear; many interacting factors play a role. Development is so much more complex than I originally thought. It would thus be simplistic to imagine that all outcomes would be related to sleep!

Nevertheless, I am most grateful that I took on this research topic. At no point during the last 3 years, did I feel that studying sleep was a pointless enterprise, even after months and months of analyses, writing up etc. Indeed, it helped me a great deal to broaden my mind. Since I did not plunge too deeply into a single area, I slowly learned to appreciate the wider context and how interesting all those different topics are.

There are two additional aspects of this PhD project that taught me a great deal and that I wish to mention here: the combined longitudinal/cross-sectional approach and the influence of a multidisciplinary team. I will now dwell briefly on each separately.

Multidisciplinary team For my PhD project and throughout my Marie Curie scholarship, I worked in a multi-disciplinary and international environment, because I also got the chance of cooperating with an industrial partner (Procter & Gamble). I actually set up a Babylab at their research site in Germany to carry out my study and spent about eight months testing at their German Innovation Centre. Moreover, I visited their headquarters in Cincinnati together with my on-site P&G supervisor, Dr. Frank Wiesemann, and took part in their training for new employees. In this context I always discussed my work with people from varied backgrounds – Dr. Frank Wiesemann is a chemist – and with completely different approaches and research questions compared to my academic ones. In fact, I believe that this variety expanded my research horizon and helped me to zero in on the most relevant questions.

Longitudinal and cross-sectional approach I am firmly convinced that longitudinal studies – in particular those which simultaneously consider a range of different aspects of development and thus include various measures – are the most important instrument we have to study development. Only deeper knowledge about how individual differences manifest over time enables us to understand their importance, their inter- action, and guides us in coming up with effective early interventions. I am very grateful that I got the chance of designing, autonomously organising and carrying out a comprehensive longitudinal study with forty infants. I am in particular grateful for the trust and support of my two supervisors, as well as to Procter & Gamble for giving me this opportunity. I believe that I learnt so much during these last three years, which will be very important and helpful in my future career. Some examples are: applying for informed consent in different countries, organising studies, recruiting, setting up a flexible Babylab, working with a tight study schedule, keeping an extensive study protocol, organising and managing data, keeping track of unexpected events, getting along well with parents and infants from different backgrounds and cultures also in order to minimise data loss.

Appendix A

Informed Consent

The informed consent was given to the parents in German.

Institution: Procter & Gamble, Schwalbach
Forscher: Susanna Brink/Manuela Mielke
Titel: **Die Assoziation von Schlaf und Aspekten der Sozialen und Kognitiven Entwicklung von Babys: Eine Längsschnittstudie**

Einverständniserklärung

Einführung: Bevor Sie zustimmen in dieser Forschungsstudie teilzunehmen, ist es wichtig, dass Sie die folgenden Erklärungen und Beschreibungen der Studie lesen und verstehen. Bei der Vorbereitung dieser Einverständniserklärung, war es notwendig eine technische Sprache zu verwenden. Bitte fragen Sie nach, sollte etwas für Sie unverständlich sein.

Bis zu 50 Kinder zwischen etwa 3 und 4 Monaten werden für diese Längsschnittstudie rekrutiert, die ungefähr 8 Monaten umfasst. Dabei werden Sie gebeten insgesamt 4 Mal eine Woche lang die nächtliche Aktivität Ihres Kindes zu messen. Wir werden Sie zu Beginn einmal zu Hause besuchen oder Sie kommen in unser Zentrum, um Ihnen alles im Detail zu erklären, sämtliche Fragebögen, das Schlaftagebuch und das Messinstrument zum Aufnehmen der Schlafaktivität (Actigraph) zu übergeben und um sicher zu gehen, dass Ihr Kind an der Studie teilnehmen kann. Dieser Besuch wird ca. 30 Minuten oder bei Bedarf länger dauern. Wir bitten Sie eine Woche lang Ihrem Kind den Actigraph anzuziehen und anschließend in unser Forschungszentrum zu kommen, um das Messinstrument, das Schlaftagebuch und die Fragebögen zurückzugeben. Bei diesem Besuch möchten wir gerne Ihrem Kind verschiedene kurze Filme und Objekte auf einem Bildschirm zeigen und dies mit speziellen Geräten (Eyetracker und Videokamera) aufnehmen. Dies gilt dann auch für eine ca. 10 minuetige Spielzeit. Dieser Besuch sollte nicht länger als eine Stunde dauern.

Ziel der Studie: In dieser Studie würden wir gerne längsschnittlich verschiedene Aspekte der sozialen und kognitiven Entwicklung von Babys untersuchen (Verarbeitung von Mengen, visuelle Aufmerksamkeit, Gedächtnis, soziale Interaktion) und wie diese von Schlaf beeinflusst werden. Ein Actigraph wird genutzt, um den Schlaf von Babys aufzunehmen. Er wird häufig zu medizinischen und Forschungszwecke verwendet und wird wie eine kleine Armbanduhr angezogen. Wenn Sie für die Studie in unser Forschungszentrum kommen, werden wir Ihrem Kind kleine Filme und Objekte auf einem Bildschirm zeigen, der an einen Eyetracker gekoppelt ist. Ein Eyetracker berechnet, wohin Ihr Kind auf dem Bildschirm Ihr Kind schaut, während es die kurzen Filme sieht.

Voraussetzung zur Teilnahme: Während des ersten Besuches werden Ihnen Fragen gestellt, die sicher stellen, dass Ihr Kind die Teilnahmebedingungen dieser Studie erfüllt. Um teilzunehmen zu können, sollte Ihr Kind zwischen 3 und 4 Monaten alt und gesund sowie nicht frühgeboren sein. Auch sollte es an keiner anderen Studie teilnehmen, welche die Ergebnisse dieser Studie beeinflussen würde. Zudem wäre es für den Erfolg dieser Studie hilfreich, wenn Ihr Baby nachts immer am gleichen Ort schläft (bspw. immer im gleichen Zimmer). Es könnte auch sein, dass wir Sie fragen für den Zeitraum der Studie in Nächten, bei denen der Actigraph verwendet wird, andere von uns bereit gestellte Windeln, zu verwenden.

Institution: Procter & Gamble, Schwalbach
Forscher: Susanna Brink/Manuela Mielke
Titel: **Die Assoziation von Schlaf und Aspekten der Sozialen und Kognitiven Entwicklung von Babys: Eine Längsschnittstudie**

Wir moechten Sie bitten, zuzustimmen, dass Sie den Studienanweisungen folgen und diese Einverständniserklärung unterzeichnen. Sollte Ihr Baby mit einer chronischen Krankheit diagnostiziert sein, welche die Sicherheit Ihres Kindes beeinträchtigt, oder sollte Ihr Baby eingeschränktes Seh- oder Hörvermögen haben, wird Ihr Kind nicht an der Studie teilnehmen können.

Prozedere: Während des ersten Besuches möchten wir Sie bitten, diese Einverständniserklärung durchzulesen, zu datieren und zu unterzeichnen. Sie haben jederzeit die Möglichkeit, Fragen zu stellen. Sie erhalten eine Kopie dieses Schriftstückes. Ihnen werden Fragen gestellt zu der Gesundheit Ihres Kindes und Ihres häuslichen Schlafarrangements. Sollte Ihr Kind geeignet für diese Studie sein, werden wir Ihnen Anweisungen für die ersten 8 Tage der Studie geben. Diese Anweisungen beziehen sich auf die Bedienung des Actigraphen und das Ausfüllen eines Schlaftagebuch und Fragebögen.

Wenn Sie nach den 8 Tagen in unser Forschungszentrum kommen, geben Sie den Actigraphen, das Schlaftagebuch und die Fragebögen zurück. Dann wird Ihr Kind einige kurze Filme und Objekte auf einem Bildschirm anschauen, während es auf Ihren Knien sitzt. Dies dauert insgesamt max. 20 Minuten und danach oder dazwischen werden wir ca. 10 Minuten Spielzeit zwischen Ihnen und Ihrem Kind aufnehmen. Diese Filmaufnahmen werden nur zur internen Studienbewertung benutzt. Nach dem Besuch erhalten Sie eine finanzielle Entschädigung für die Fahrt und die Zeit, die Sie im Forschungszentrum waren.

Die 8 Tage Aufnahme der Schlafaktivitaet sowie der zweite Besuch werden alle 2 Monate wiederholt, bis Ihr Kind 10 Monate alt ist. Jeden Monat werden wir Sie bitten die Fragebögen ausfüllen.

Freiwillige Teilnahme: Ihre Entscheidung mit Ihrem Kind an dieser Forschungsstudie teilzunehmen ist freiwillig. Sie können die Teilnahme jederzeit ohne Angabe von Gründen (mit Ausnahme eventuell auftretender Nebenwirkungen, die anzugeben sind) und ohne nachteilige Folgen abbrechen. Wir bitten jedoch zu bedenken, daß die Teilnahme an dieser Studie nur dann einen sinnvollen Beitrag zum Gesamtergebnis leistet, wenn das Baby den gesamten Test durchläuft. Wir würden uns freuen, wenn Sie uns im Falle eines Abbruchs aus anderen Gründen darüber informieren würden, ob testbezügliche Gründe zu Ihrem Entschluß geführt haben.
Unter folgenden Bedingungen könnte es sein, dass der Studienleiter Ihr Kind der Studienteilnahme entbinden wird: die Teilnahme schadet ihrem Kind aus medizinischen Gründen (1), Sie beachten nicht die Anweisungen (2), Ihr Kind erfüllt nicht die Bedingungen, die zur Studienteilnahme notwendig sind (3), oder die Studie wird abgebrochen (4).

Institution: Procter & Gamble, Schwalbach
Forscher: Susanna Brink/Manuela Mielke
Titel: **Die Assoziation von Schlaf und Aspekten der Sozialen und Kognitiven Entwicklung von Babys: Eine Längsschnittstudie**

Risiken und Unannehmlichkeiten: Es werden für Ihr Kind keine Risiken erwartet. Sämtliche in dieser Studie verwendeten Methoden wurden bereits ausführlich in Studien mit Babys getestet. Sollten Sie jedoch zu irgendeinem Zeitpunkt besorgt sein, dass Ihr Kind Stress oder negative Erfahrungen auf Grund der Studie empfindet, können Sie den Gebrauch des Schlafmonitors stoppen und die Teilnahme an der Studie beendigen. Sollten im Zusammenhang der Studie wesentliche neue Erkenntnisse gefunden werden, die zeigen, dass es für Ihr Kind von Nachteil ist an der Studie weiterhin teilzunehmen, werden wir Ihnen diese Informationen unverzüglich mitteilen.

Vorteile: Die Teilnahme an der Studie bringt Ihnen keinen größeren Nutzen, aber die Ergebnisse könnten zum wissenschaftlichen Fortschritt auf diesem Gebiet beitragen.

Alternative Testverfahren: In dieser Studie erfahren alle Teilnehmer die gleiche Behandlung.

Vertraulichkeit: Informationen über Sie und Ihr Kind, die im Zusammenhang mit der Studie gesammelt werden, werden immer vertraulich und nach den Richtlinien von P&G behandelt. Daten können an in- und/oder ausländische Bundesoberbehörden weitergegeben werden. Die Weitergabe erfolgt nur zu Zwecken der Prüfung und in der Regel ausschließlich in anonymisierter Form. Es ist gewährleistet, dass die personenbezogenen Daten absolut vertraulich behandelt und nicht in die Öffentlichkeit gelangen werden.Sollten die Ergebnisse dieser Studie publiziert werden, wird der Name ihres Kindes nicht verwendet. Sie haben die Möglichkeit die Studiendaten Ihres Kindes nach Beendigung der Studie einzusehen.

Medizinische Behandlung: Bitte informieren Sie uns, sollte Ihr Kind auf Grund von Krankheit oder Verletzung Medikamente bekommen, welche die Resultate der Studie verändern könnten.

In diesem Fall oder sollten Sie andere Fragen zur Studie haben, kontaktieren Sie bitte Manuela Mielke unter 06196 895063 (Buero) oder 01722742772 (Handy).

Entschädigung: Ich wurde über die finanzielle Entschädigung für die Teilnahme an der Studie informiert. Nach jedem Besuch im Forschungszentrum werde ich eine Entschädigung von 20 Euro erhalten und Windeln für den Zeitraum der Studie.

Institution: Procter & Gamble, Schwalbach
Forscher: Susanna Brink/Manuela Mielke
Titel: **Die Assoziation von Schlaf und Aspekten der Sozialen und Kognitiven Entwicklung von Babys: Eine Längsschnittstudie**

Einverständnis: Ich habe schriftliche Informationen zur Studie erhalten und hatte genügend Zeit, diese zu lesen. Zudem hat man mich mündlich umfassend über die Art, den Sinn und die Konsequenzen der Studie aufgeklärt, insbesondere, was das Ziel der Studie, die Ausführung, Vorteile und Risiken betrifft. Alle meine Fragen wurden ausführlich beantwortet und ich habe nun keine offenen Fragen mehr. Ich weiß, dass ich zu jedem Zeitpunkt der Studie weitere Fragen stellen kann.

Ich gebe willentlich mein Einverständnis, dass mein Kind an dieser Studie teilnimmt. Ich weiß, dass ich jederzeit dieses widerrufen und die Teilnahme beenden kann. Ich stimme zu, dass Daten über mein Kind gesammelt werden. Auch stimme ich zu, dass die gesammelten Daten anonymisiert an autorisierte Spezialisten zur Datenverarbeitung und wissenschaftlichen Analyse sowie zur Überarbeitung weitergegeben werden dürfen.

Ich erkläre, dass ich mein Einverständnis gebe, dass meine Daten im Rahmen der Studie gesammelt werden dürfen und ich willige ein, dass Personen, die an der Studie mitwirken die Daten aus wissenschaftlichen Gründen anschauen dürfen. Letztendlich gebe ich auch mein Einverständnis, dass die Ergebnisse der Forschungsstudie wissenschaftlich und in anonymisierter Form veröffentlicht werden dürfen.

Ich bin damit einverstanden, dass während der Studie Filmaufnahmen von mir und meinem unten bezeichneten Kind angefertigt werden und diese nur zur internen Studienzwecken verwendet werden.

Name des Kindes (in Druckbuchstaben): Vorname Mittlere Initialen Nachname

---

Name des 1. Erziehungsberechtigten: Vorname Mittlere Initialen Nachname

---

Unterschrift des 1. Erziehungsberechtigten Datum

Name des 2. Erziehungsberechtigten: Vorname Mittlere Initialen Nachname

---

Unterschrift des 2. Erziehungsberechtigten Datum

Unterschrift Studienleiter/in oder Vertreter/in Datum

Teilnehmernummer | | | |

Appendix B

Sleep diary

One page of the German sleep diary and a translated English version is included. This corresponds to one night and day of sleep recording.

TAG 1

Zeit des Zubettgehens:	Zeit des Aufwachens:
[__________:__________]	[__________:__________]

- **War der Actigraph angeschaltet?** Ja [ ] Nein [ ]

Wenn nicht, bitte erklären Sie warum nicht:

- **War diese Nacht eine typische Nacht für Ihr Baby?** Ja [ ] Nein [ ]

Falls nicht, bitte beschreiben Sie im Detail:

- **Gibt es eine Änderung des Gesundheitszustandes?** Ja [ ] Nein [ ]

Wenn ja, bitte beschreiben Sie:

- **Haben Sie Ihr Kind wach in das Bettchen gelegt?** Ja [ ] Nein [ ]

- **Wann haben Sie Ihr Baby zum letzten Mal vor dem Schlafen gefüttert?** [__________:__________]

- **Haben Sie Ihr Baby in der Nacht aus dem Bett geholt?** Ja [ ] Nein [ ]

Wenn ja, bitte notieren Sie die Details zu jedem Ereignis:

Ereignis 1	Aus dem Bett: [_____:_____]	Zurück ins Bett: [_____:_____]
	Gefüttert? [ ]	Windel gewechselt? [ ]
Ereignis 2	Aus dem Bett: [_____:_____]	Zurück ins Bett: [_____:_____]
	Gefüttert? [ ]	Windel gewechselt? [ ]
Ereignis 3	Aus dem Bett: [_____:_____]	Zurück ins Bett: [_____:_____]
	Gefüttert? [ ]	Windel gewechselt? [ ]
Ereignis 4	Aus dem Bett: [_____:_____]	Zurück ins Bett: [_____:_____]
	Gefüttert? [ ]	Windel gewechselt? [ ]

Am Tag:

Ereignis 1	Eingeschlafen: [_____:_____]	Aufgewacht: [_____:_____]
Ereignis 2	Eingeschlafen: [_____:_____]	Aufgewacht: [_____:_____]
Ereignis 3	Eingeschlafen: [_____:_____]	Aufgewacht: [_____:_____]
Ereignis 4	Eingeschlafen: [_____:_____]	Aufgewacht: [_____:_____]

Kommentare oder mehr Ereignisse:

Date: ________________________

Day 1

Time of bedtime:	Time awake/outof bed (morning):
[__________:__________]	[__________:__________]

- **Actiwatch applied?** Yes [ ] No [ ]

If no, explain why not:

Yes [ ] No [ ]

- **Was this a typical night for your infants?**

If no, explain why not:

Yes [ ] No [ ]

- **Change in health?**

If yes, describe:

Yes [ ] No [ ]

- **Was your baby awake when you put it into the bed in the evening?**

Awakening 1	Out of bed: [_____:_____] Baby fed? [ ]	Return to bed: [_____:_____] Nappy change? [ ]
Awakening 2	Out of bed: [_____:_____] Baby fed? [ ]	Return to bed: [_____:_____] Nappy change? [ ]
Awakening 3	Out of bed: [_____:_____] Baby fed? [ ]	Return to bed: [_____:_____] Nappy change? [ ]
Awakening 4	Out of bed: [_____:_____] Baby fed? [ ]	Return to bed: [_____:_____] Nappy change? [ ]

Am Tag:

Nap 1	Fell asleep: [_____:_____]	Woke up: [_____:_____]
Nap 2	Fell asleep: [_____:_____]	Woke up: [_____:_____]
Nap 3	Fell asleep: [_____:_____]	Woke up: [_____:_____]
Nap 4	Fell asleep: [_____:_____]	Woke up: [_____:_____]

Comments or more awakenings / naps:

Appendix C

Sleep questionnaire

One page of the translated sleep questionnaire (German) and the English version is included.

Schlaffragebogen

1. Wo schläft Ihr Baby?

- In einer Krippe im eigenen Zimmer [ ]
- In einer Krippe im Schlafzimmer der Eltern [ ]
- Im elterlichen Bett [ ]
- Mit einem Geschwister in einem Bett [ ]

- Bitte spezifizieren Sie, wenn kein Punkt zutrifft:
  ____

2. In welcher Position schläft ihr Baby die meiste Zeit über?

- Auf dem Bauch [ ]
- Auf der Seite [ ]
- Auf dem Rücken [ ]

3. Wie lange schläft ihr Baby in der NACHT (zwischen 7 Uhr abends und 7 Uhr morgens)?

Stunden: ______________ Minuten: _________________

4. Wie lange schläft ihr Baby am TAG (zwischen 7 Uhr morgens und 7 Uhr abends)?

Stunden: ______________ Minuten: _________________

5. Wie oft wacht ihr Baby normalerweise auf pro Nacht auf?
____

6. Wie lange ist ihr Baby nachts wach (von 10 Uhr abends bis 6 Uhr morgens)?

Stunden: ______________ Minuten: _________________

7. Wie lange dauert es, bis ihr Baby abends zur Ruhe kommt zum Schlafen?

Stunden: ______________ Minuten: _________________

8. Legen Sie Ihr Baby wach oder schlafend in seine Krippe?

Wach / Schlafend

9. Wie schläft ihr Baby ein?

- Beim Füttern [ ]
- Beim Wiegen [ ]
- Auf dem Arm [ ]
- Alleine im Bett [ ]
- Im Bett in der Nähe der Eltern [ ]

10. Um wie viel Uhr schläft Ihr Kind gewöhnlicherweise abends ein?

____

11. Sehen Sie das Schlafverhalten Ihres Babys als problematisch an?

- Ja, das ist ein großes Problem [ ]
- Es ist ein kleines Problem [ ]
- Nein, ich sehe es nicht als problematisch [ ]

12. Nehmen Sie ihr Baby zu sich ins Bett, wenn es aufwacht? Ja [ ] / Nein [ ]

13. Warten Sie bis Ihr Baby eingeschlafen ist, [ ]
oder verlassen Sie den Raum zuvor? [ ]

14. Hat ihr Baby ein abendliches Ritual?
Wenn ja, wie sieht diese aus? ___________________________________

15. Über Sie als Eltern:

- Genießen Sie es ihr Baby ins Bett zu bringen? Ja [ ] / Nein [ ]
- Beobachten Sie gerne ihr Baby beim Schlafen? Ja [ ] / Nein [ ]
- Erleben Sie einen Schlafmangel, der ihr tägliches Leben beeinträchtigt?

  Ja [ ] / Nein [ ]
- Erleben Sie ein ständiges Schlafdefizit? Ja [ ] / Nein [ ]
- Beeinträchtigt ihr Schlafdefizit Ihre Beziehung? Ja [ ] / Nein [ ]
- Falls Sie ein Schlafdefizit haben, hatten Sie das bereits bevor ihr Baby geboren wurde?
  Ja [ ] / Nein [ ]

Falls Sie möchten, können Sie hier noch Anmerkungen machen:

1. Where does your child sleep?

- Infant crib in a separate room [ ]
- Infant crib in parents' room [ ]
- In parents' bed [ ]
- Infant crib in room with sibling [ ]

- Other, please specify: ______________________________

2. In what position does your child sleep most of the time?

- On his/her belly [ ]
- On his/her side [ ]
- On his/her back [ ]

3. How much time does your child spend in sleep during the night (between 7 in the evening and 7 in the morning)?

Hours: ______________ Minutes: _________________

4. How much time does your child spend in sleep during the day (between 7 in the morning and 7 in the evening)?

Hours: ______________ Minutes: _________________

5. Average number of awakenings per night: _______________________

6. How much time during the nights does your child spend in wakefulness?

Hours: ______________ Minutes: _________________

7. How long does it take to put your baby to sleep in the evening?

Hours: ______________ Minutes: _________________

8. How do you put your baby into bed?

Awake / Asleep

9. How does your baby fall asleep?

- While feeding [ ]
- Being rocked [ ]
- Being held [ ]
- In bed alone [ ]
- In bed near parent [ ]

10. How long does your baby usually take toĺ fall asleep for the night?

____

11. Do you consider your child's sleep as a problem?

- A very serious problem [ ]
- A small problem [ ]
- Not a problem at all [ ]

12. Do you take your baby into your own bed when she/he wakes up in the night?
Yes [ ] / No [ ]

13 Do you wait until your baby is asleep, [ ]
or do you leave the room before? [ ]

14. Does your baby have an evening ritual?
If yes, please describe? _________________________________

15. About you as a parent:

- Do you enjoy bringing your baby to bed? Yes [ ] / No [ ]
- Do you enjoy to observe your sleeping baby? Yes [ ] / No [ ]
- Do you experience a lack of sleep, which impacts your daily activities?
Yes [ ] / No [ ]
- Do you experience a permanent lack of sleep? Yes [ ] / No [ ]
- If the latter question was yes, does this lack of sleep influence your relationship? Yes [ ] / No [ ]
- If you experience a lack of sleep, was that already the case before your baby was born? Yes [ ] / No [ ]

I you want to write down any comments, please feel free to do so here:

Appendix D

Questionnaire on social background

The questionnaire on the social background of the infants, which parents filled in at the beginning of the study, is included in German and English.

Name des Kindes: ________________________ **Datum: _____________**

Hintergrundinformation

Ihr Name:

Ihre Rolle in der Familie	Mutter / Vater / Großelternteil / Andere:___________________________
Name des Kindes:	____
Geburtsdatum:	____
Geschlecht	Männlich [ ] Weiblich [ ]
Anzahl derGeschwister:	____ Sind diese älter oder jünger?

Informationen zur Mutter:

Hoechster Abschluss

- Universitätsabschluss oder Äquivalent [ ]
- FH / Ausbildung etc. [ ]
- Realschulreife [ ]
- Hauptschulabschluss [ ]
- Keine Angabe [ ]

Beruf der Mutter: ____

Informationen zum Vater:

Hoechster Abschluss

- Universitätsabschluss oder Äquivalent [ ]
- FH / Ausbildung etc. [ ]
- Realschulreife [ ]
- Hauptschulabschluss [ ]
- Keine Angabe [ ]

Beruf des Vaters: ____

Name of the child: ________________________ **Date: _____________**

Information on the background

Your name:

Your role in the family	Mother / Father / Grandparent / Other:___________________________
Name of the child:	____
Date of birth:	____
Gender	Male [ ] Female [ ]
Number of siblings	____
	Are they younger or older?

Information on the mother:

Highest degree

- University degree [ ]
- College [ ]
- Secondary school [ ]
- Main school [ ]
- Prefer not to say [ ]

Occupation of the mother: ____

Information on the father:

Highest degree

- University degree [ ]
- College [ ]
- Secondary school [ ]
- Main school [ ]
- Prefer not to say [ ]

Occupation of the father: ____

Appendix E

Ages & Stages questionnaire

One page of the translated Ages & Stages (German) and the English version is included for 4, 6, 8, and 10 months.

4 MONATE

	JA	NEIN
1. Macht Ihr Baby gelegentlich Töne, wenn es sich wohlfühlt, bspw. glucksen?		
2. Wenn Sie einmal nicht mehr in Sichtweite waren, lächelt ihr Baby oder reagiert aufgeregt, sobald es Sie wieder sieht?		
3. Hört ihr Baby auf zu weinen, sobald es die Stimme von einer anderen Person außer Ihnen hört?		
4. Macht Ihr Baby hohe Jauchzer?		
5. Lacht Ihr Baby?		
6. Macht ihr Baby Töne oder Geräusche, wenn es Spielzeuge oder Leute betrachtet?		

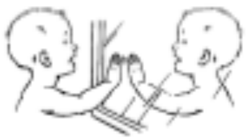
	JA	NEIN
1. Bewegt Ihr Baby seinen Kopf von einer Seite zur anderen, wenn es auf dem Rücken liegt?		
2. Liegt Ihr Baby auf dem Bauch und hält seinen Kopf nach oben, legt es eher den Kopf langsam wieder auf den Boden, anstatt ihn fallen zu lassen?		
3. Wenn ihr Baby auf dem Bauch liegt, hält es seinen Kopf mindestens 15 Sekunden nach oben, so dass sein Kinn in etwa		

7-8 cm über dem Boden ist? 		
4. Wenn Ihr Baby auf dem Bauch liegt, hält es seinen Kopf nach oben und schaut umher? (es kann sich dabei auf den Armen aufstützen) 		
5. Wenn Sie Ihr Baby in einer Sitzposition halten, hält es seinen Kopf ruhig?		
6. Wenn Ihr Baby auf dem Rücken liegt, kann es seine Hände vor der Brust zusammenbringen, so dass sich die Finger berühren? 		

	JA	NEIN
1. Öffnet Ihr Baby seine Hand, wenn auch nur teilweise (anstatt sie zur Faust zu ballen, wie als Neugeborenes)? 		
2. Wenn Sie ein Spielzeug in die Hand Ihres Babys legen, schüttelt es dieses herum, wenn auch nur kurz?		
3. Greift und zieht Ihr Baby gelegentlich an seiner Kleidung?		
4. Wenn Sie Ihrem Baby ein Spielzeug in die Hand geben, hält es		

dieses für mindestens eine Minute fest, wobei es dieses anschaut, herumschüttelt, oder versucht es zu essen?		
5. Wenn Ihr Baby in einer Sitzposition gehalten wird oder auf dem Bauch liegt, greift oder kratzt es die Oberfläche vor ihm?		
6. Wenn Sie Ihr Baby in einer Sitzposition festhalten, versucht es an ein nahe liegendes Spielzeug zu kommen, auch, wenn seine Hände es nicht berühren können? 		

	JA	NEIN
1. Wenn Sie ein Spielzeug etwa 25 cm vor den Augen Ihres Babys hin und her bewegen, folgt es dem Spielzeug mit den Augen und dreht dabei manchmal seinen Kopf in diese Richtung? 		
2. Wenn Sie ein kleines Spielzeug langsam auf und ab bewegen vor den Augen Ihres Babys, folgt es dem Spielzeug mit den Augen?		
3. Wenn Sie ihr Baby in einer Sitzposition halten, schaut es ein Spielzeug (ungefähr so groß, wie eine Tasse oder eine Rassel) an, das Sie vor ihm auf den Tisch oder auf den Boden legen?		
4. Wenn Sie Ihrem Baby ein Spielzeug in die Hand geben, schaut es das an?		

5. Wenn Sie Ihrem Baby ein Spielzeug in die Hand geben, nimmt es dieses in den Mund?		
6. Wenn Sie ein Spielzeug über ihrem Baby baumeln lassen, während es auf dem Rücken liegt, greift es manchmal danach? 		

	JA	NEIN
1. Schaut Ihr Baby seine Hände an?		
2. Wenn Ihr Baby seine Hände zusammen hält, spielt es mit seinen Fingern?		
3. Wenn Ihr Baby die Brust oder Flasche sieht, weiß es, dass es bald gefüttert wird?		
4. Hilft Ihr Baby die Flasche mit beiden Händen zu halten, oder hält es die Brust mit einer Hand?		
5. Bevor Sie Ihr Baby anlächeln oder zu ihm sprechen, lächelt es wenn es Sie in der Nähe sieht?		
6. Wenn es vor einem Spiegel ist, lächelt oder kräht ihr Baby sich an?		

6 Monate

	JA	MANCHMAL	NEIN
1. Macht ihr Baby Jauchzer?			
2. Wenn es mit Tönen spielt, grunzt oder knurrt ihr Baby oder macht andere tiefe Laute?			
3. Wenn Sie ihr Baby rufen aber nicht in Sichtweite sind, schaut es in die Richtung Ihrer Stimme?			
4. Wenn Ihr Baby einen Lärm hört, dreht Ihr Baby sich, um zu sehen, woher der Lärm kam?			
5. Macht ihr Baby Laute wie ‘da’, ‘ga’, ‘ka’ und ‘ba’?			
6. Wenn Sie die Laute kopieren, die Ihr Baby macht, wiederholt es sie nochmal im Anschluss?			
7. Wenn Ihr Baby auf dem Rücken liegt, kann es seine Füße so hoch heben, dass es sie sehen kann?			
8. Wenn Ihr Baby auf dem Bauch liegt, kann es seine Arme ausstrecken und seinen ganzen Oberkörper hochheben?			
9. Rollt Ihr Baby vom Rücken auf den Bauch und holt es dann seine Arme von unter seinem Bauch nach oben?			

	JA	MANCHMAL	NEIN
10. Wenn Sie ihr Baby auf den Boden setzen, lehnt es auf seinen Händen, wenn es sitzt? (Sollte es schon sitzen, ohne sich anlehnen zu müssen, markieren Sie bitte “Ja”) 			
11. Wenn Sie beide Hände Ihres Babys halten, um ihm eine Balance zu geben, hält es sein eigenes Gewicht, während es steht? 			
12. Kann Ihr Baby eine Krabbelposition einnehmen, wobei es sein Gewicht auf den Händen und Knien hat? 			
13. Wenn Sie Ihrem Baby ein Spielzeug in die Hand geben, hält es dieses für mindestens eine Minute fest, wobei es dieses anschaut, herumschüttelt, oder in den Mund nimmt?			
14. Greift ihr Baby nach einem Spielzeug und gebraucht dabei beide Hände?			
15. Versucht ihr Baby nach einem Krümel oder eine Erbse zu greifen und berührt es mit seinen Fingern oder seiner Hand? (Wenn es bereits kleines Objekt in erbsengröße greifen und hochnehmen kann, kreuzen Sie bitte hier			

"Ja" an) 			
	JA	MANCHMAL	NEIN
16. Nimmt ihr Baby ein kleines Spielzeug hoch, hält es in der Handfläche und umschließt es mit den Fingern? 			
17. Versucht ihr Baby einen Krümel oder eine Rosine hochzunehmen, indem es den Daumen und die Finger in einer 'Rechenposition' hält, auch wenn es nicht fähig ist das Stück aufzuheben? (Wenn es das Stück schon aufhebt, antworten Sie bitte mit "Ja") 			
18. Hebt Ihr Baby ein kleines Spielzeug mit nur einer Hand auf? 			
19. Wenn ein Spielzeug vor Ihrem Baby liegt, greift es danach mit beiden Händen?			
20. Wenn Ihr Baby auf dem Rücken liegt, dreht es seinen Kopf, nachdem es ein Spielzeug fallen gelassen hat? (Wenn es das Spielzeug schon aufhebt, kreuzen Sie bitte "Ja" an)			
21. Wenn Ihr Baby auf dem Rücken liegt, versucht es ein Spielzeug zu greifen, wenn es dieses fallen gelassen hat?			

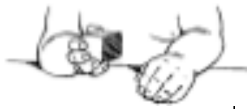
22. Hebt ihr Baby ein Spielzeug auf und nimmt es in den Mund? 			
	JA	MANCHMAL	NEIN
23. Nimmt Ihr Baby ein Spielzeug von einer Hand in die andere? 			
24. Schlägt Ihr Baby beim Spielen ein Spielzeug immer wieder auf einen Tisch oder den Boden? 			
25. Wenn es vor einem Spiegel ist, lächelt oder kräht ihr Baby sich an? 			
26. Reagiert Ihr Baby auf Fremde anders als auf Sie oder andere Familienmitglieder? (Reaktionen gegenüber Fremden können beinhalten, dass es sie anstarrt, die Stirn runzelt, sich abwendet oder weint)			
27. Wenn es auf dem Rücken liegt, spielt Ihr Baby, indem es seinen Fuß in die Hand nimmt? 			

28. Wenn es vor einem großen Spiegel ist, streckt Ihr Baby sich, um an das Glas zu kommen? 			
29. Wenn Ihr Baby auf dem Rücken liegt, nimmt es seinen Fuß in den Mund? 			
30. Versucht Ihr Baby an ein Spielzeug zu kommen, dass für es nicht zu erreichen ist? (Es ist möglich, dass es rollt, auf dem Bauch robbt oder krabbelt, um an das Spielzeug zu kommen)			

8 Monate

	JA	MANCHMAL	NEIN
Wenn Sie ihr Baby rufen aber nicht in Sichtweite sind, schaut es in die Richtung Ihrer Stimme?			
Wenn Ihr Baby einen Lärm hört, dreht Ihr Baby sich, um zu sehen, woher der Lärm kam?			
Wenn Sie die Töne kopieren, die Ihr Baby macht, wiederholt es sie nochmal im Anschluss?			
Macht ihr Baby Töne wie ‘da’, ‘ga’, ‘ka’ und ‘ba’?			
Antwortet Ihr Baby auf die Ton Ihrer Stimme und hält zumindest kurz inne, wenn Sie zu ihm “Nein-Nein” sagen?			
Macht ihr Baby zwei ähnliche Laute hintereinander, wie “ba-ba”, “da-da” oder ”ga-ga”? (die Töne müssen nichts bedeuten)			
Wenn Sie ihr Baby auf den Boden setzen, lehnt es auf seinen Händen, wenn es sitzt? (sollte es schon sitzen, ohne sich anlehnen zu müssen, markieren Sie bitte “Ja”) 			
Rollt Ihr Baby vom Rücken auf den Bauch und holt es dann seine Arme von unter seinem Bauch nach oben?			

	JA	MANCHMAL	NEIN
Kommt Ihr Baby in eine Krabbelposition mit den Händen und Knien auf dem Boden? 			
Wenn Sie beide Hände Ihres Babys halten, um ihm eine Balance zu geben, hält es sein eigenes Gewicht, während es steht? 			
Wenn Ihr Baby auf dem Boden sitzt, sitzt es dann möglicherweise für einige Minuten, ohne dass es sich auf den Händen aufstützt? 			
Wenn Sie Ihr Baby neben Möbel oder die Gitterstäbe seiner Krippe stellen, kann es stehen, ohne seinen Oberkörper zur Unterstützung anzulehnen? 			
Versucht ihr Baby nach einem Krümel oder eine Rosine zu greifen und berührt es mit seinen Fingern oder seiner Hand? (wenn es bereits kleine Objekt in erbsengröße greifen und hochnehmen kann, kreuzen Sie bitte hier "Ja" an) 			

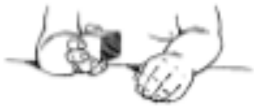
Nimmt ihr Baby ein kleines Spielzeug hoch, hält es in der Handfläche und umschließt es mit den Fingern? 			
	JA	MANCHMAL	NEIN
Versucht ihr Baby einen Krümel oder eine Rosine hochzunehmen, indem es den Daumen und die Finger in einer ‘Rechenposition’ hält, auch wenn es nicht nicht fähig ist das Stück aufzuheben? (Wenn es das Stück schon aufhebt, antworten Sie bitte mit “Ja”) 			
Hebt Ihr Baby ein kleines Spielzeug mit nur einer Hand auf? 			
Hebt ihr Baby einen Krümel oder eine Rosine auf, indem es den Daumen und die Finger in einer ‘Rechenposition’ hält? (Wenn es das Stück schon aufhebt, antworten Sie bitte mit “Ja”) 			
Versucht ihr Baby einen Krümel oder eine Rosine hochzunehmen, indem es den Daumen und die Finger in einer ‘Rechenposition’ hält, auch wenn es nicht fähig ist das Stück aufzuheben? (Wenn es das Stück schon aufhebt, antworten Sie bitte mit “Ja”) 			

Hebt ihr Baby ein Spielzeug auf und nimmt es in den Mund? 			
Wenn Ihr Baby auf dem Rücken liegt, versucht es ein Spielzeug zu greifen, nachdem es dieses fallen gelassen hat?			
	JA	MANCHMAL	NEIN
Schlägt ihr Baby beim Spielen ein Spielzeug immer wieder auf den Boden oder einen Tisch? 			
Nimmt Ihr Baby ein Spielzeug von einer Hand in die andere? 			
Nimmt ihr Baby zwei Spielzeuge, jeweils eines in jede Hand, und behält sie für etwa eine Minute? 			
Wenn Ihr Baby ein Spielzeug in der Hand hält, schlägt es dieses gegen ein anderes Spielzeug auf dem Tisch oder dem Boden? 			
Wenn es auf dem Rücken liegt, spielt Ihr Baby indem es seinen Fuß in die Hand nimmt? 			
Wenn es vor einem großen Spiegel ist, streckt Ihr Baby sich, um an den Spiegel zu kommen?			

			
Versucht Ihr Baby an ein Spielzeug zu kommen, dass für es nicht zu erreichen ist? (es ist möglich, dass es rollt, auf dem Bauch robbt oder krabbelt, um an das Spielzeug zu kommen)			
Wenn Ihr Baby auf dem Rücken liegt, nimmt es seinen Fuß in den Mund? 			
Trinkt ihr Baby Wasser, Saft oder angerührte Milch aus seiner Tasse, wenn Sie diese halten?			
Isst ihr Baby selbständig einen Cracker oder einen Keks?			

10 Monate

	JA	MANCHMAL	NEIN
Macht ihr Baby Laute wie ‘da’, ‘ga’, ‘ka’ und ‘ba’?			
Wenn Sie die Laute kopieren, die Ihr Baby macht, wiederholt es sie nochmal im Anschluss?			
Macht ihr Baby zwei ähnliche Laute hintereinander, wie “ba-ba”, “da-da” oder ”ga-ga”? (die Töne müssen nichts bedeuten)			
Wenn Sie Ihr Baby danach fragen, spielt es zumindest ein Kinderspiel, sogar, wenn Sie ihm die Aktivität nicht vormachen (so etwas wie “Bye-bye”, “Kuck=kuck”, “klatsch in die Hände“ oder “So Groß!”)			
Hört ihr Baby auf einfache Sätze, wie “Komm her”, “Gib es mir” oder “Leg es zurück”, ohne dass Sie eine dazugehörende Geste benutzen?			
Sagt ihr Baby drei Worte, wie “Mama”, “Dada” und “Baba”? (Ein Wort ist ein oder mehrere Laute, die Ihr Baby immer wieder sagt und die etwas bedeuten)			
Wenn Sie beide Hände Ihres Babys halten, um ihm eine Balance zu geben, hält es sein eigenes Gewicht, während es steht? 			

	JA	MANCHMAL	NEIN
Wenn Ihr Baby auf dem Boden sitzt, sitzt es dann möglicherweise für einige Minuten, ohne dass es sich auf den Händen aufstützt? 			
Wenn Sie Ihr Baby neben Möbel oder die Gitterstäbe seiner Krippe stellen, kann es stehen, ohne seinen Oberkörper zur Unterstützung anzulehnen? 			
Wenn Ihr Baby sich an Möbeln festhält, bückt es sich nach unten, um ein Spielzeug auf dem Boden aufzuhaben, und kommt dann zurück in eine Stehposition? 			
Wenn Ihr Baby sich an Möbeln festhält, lässt es sich manchmal kontrolliert heruntersinken (ohne zu fallen oder plötzlich zu sitzen)?			
Macht ihr Baby Schritte, während es sich an Möbeln festhält?			
Hebt Ihr Baby ein kleines Spielzeug mit nur einer Hand auf? 			
Hebt Ihr Baby einen Krümel oder eine Rosine auf und hat dabei den Daumen und die Finger in einer “Rechenhaltung”? (Wenn es bereits das 			

Stück anderweitig hochheben kann, antworten Sie bitte mit “Ja”)			
	JA	MANCHMAL	NEIN
Hebt ihr Baby ein kleines Spielzeug nur mit den Fingerspitzen hoch? (Sie sollten noch einen Freiraum zwischen der Handfläche und dem Spielzeug sehen) 			
Nach einigen Versuchen, hebt Ihr Baby ein Stück Faden hoch mit dem Daumen und dem Zeigefinger? (Der Faden ist möglicherweise an einem Spielzeug festgemacht) 			
Hebt Ihr Baby einen Krümel oder eine Rosine mit den Fingerspitzen hoch? (Es kann dabei den Arm oder die Hand auf den Tisch ablegen) 			
Legt Ihr Baby ein kleines Spielzeug ab, ohne es fallen zu lassen und nimmt dann seine Hand von dem Spielzeug?			
Nimmt Ihr Baby ein Spielzeug von einer Hand in die andere? 			
Nimmt ihr Baby zwei Spielzeuge, jeweils eines in jede Hand, und behält sie für etwa eine Minute? 			

Wenn Ihr Baby ein Spielzeug in der Hand hält, schlägt es dieses gegen ein anderes Spielzeug auf dem Tisch oder dem Boden? 			
	JA	MANCHMAL	NEIN
Wenn Ihr Baby in beiden Händen jeweils ein Spielzeug hält, klatscht es sie zusammen?			
Versucht Ihr Baby einen Krümel oder eine Rosine zu bekommen, das in einer Flasche ist (So etwas wie einer Babyflasche)?			
Wenn es Sie beobachtet hat, wie Sie ein kleines Spielzeug unter einem Blatt Papier oder einem Stück Stoff versteckt haben, findet Ihr Baby das Spielzeug? (Seien Sie sicher, dass das Spielzeug vollständig verborgen ist)			
Wenn Ihr Baby auf dem Rücken liegt, nimmt es seinen Fuß in den Mund? 			
Trinkt ihr Baby Wasser, Saft oder angerührte Milch au seiner Tasse, wenn Sie diese halten?			
Isst ihr Baby selbständig einen Cracker oder einen Keks?			
Wenn Sie nach einem Spielzeug fragen und dabei die Hand ausgestreckt haben, gibt Ihr Baby Ihnen das Spielzeug, auch wenn es dieses nicht loslässt? (Wenn es das Spielzeug bereits			

loslässt, antworten Sie bitte mit “Ja”)			
Wenn Sie Ihr Baby anziehen, streckt es seinen Arm durch einen Ärmel sobald der Arm in dem Ärmel ist?			
Wenn Sie nach einem Spielzeug fragen und dabei die Hand ausgestreckt haben, gibt Ihr Baby Ihnen das Spielzeug und legt es in Ihrer Hand ab?			

![ASQ-3]

4 Month Questionnaire

3 months 0 days through 4 months 30 days

On the following pages are questions about activities babies may do. Your baby may have already done some of the activities described here, and there may be some your baby has not begun doing yet. For each item, please fill in the circle that indicates whether your baby is doing the activity regularly, sometimes, or not yet.

Important Points to Remember:

- ☑ Try each activity with your baby before marking a response.
- ☑ Make completing this questionnaire a game that is fun for you and your baby.
- ☑ Make sure your baby is rested and fed.
- ☑ Please return this questionnaire by ______________.

Notes:

____

____

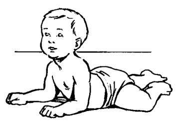
____

____

COMMUNICATION

	YES	SOMETIMES	NOT YET	
1. Does your baby chuckle softly?	○	○	○	____
2. After you have been out of sight, does your baby smile or get excited when he sees you?	○	○	○	____
3. Does your baby stop crying when she hears a voice other than yours?	○	○	○	____
4. Does your baby make high-pitched squeals?	○	○	○	____
5. Does your baby laugh?	○	○	○	____
6. Does your baby make sounds when looking at toys or people?	○	○	○	____
			COMMUNICATION TOTAL	____

GROSS MOTOR

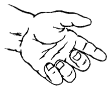
	YES	SOMETIMES	NOT YET	
1. While your baby is on his back, does he move his head from side to side?	○	○	○	____
2. After holding her head up while on her tummy, does your baby lay her head back down on the floor, rather than let it drop or fall forward?	○	○	○	____
3. When your baby is on his tummy, does he hold his head up so that his chin is about 3 inches from the floor for at least 15 seconds? 	○	○	○	____
4. When your baby is on her tummy, does she hold her head straight up, looking around? *(She can rest on her arms while doing this.)* 	○	○	○	____

GROSS MOTOR *(continued)*

	YES	SOMETIMES	NOT YET	
5. When you hold him in a sitting position, does your baby hold his head steady?				___
6. While your baby is on her back, does your baby bring her hands together over her chest, touching her fingers? 				___

GROSS MOTOR TOTAL ___

FINE MOTOR

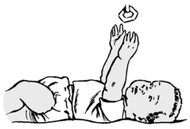
	YES	SOMETIMES	NOT YET	
1. Does your baby hold his hands open or partly open (rather than in fists, as they were when he was a newborn)? 				___
2. When you put a toy in her hand, does your baby wave it about, at least briefly?				___
3. Does your baby grab or scratch at his clothes?				___
4. When you put a toy in her hand, does your baby hold onto it for about 1 minute while looking at it, waving it about, or trying to chew it?				___
5. Does your baby grab or scratch his fingers on a surface in front of him, either while being held in a sitting position or when he is on his tummy?				___
6. When you hold your baby in a sitting position, does she reach for a toy on a table close by, even though her hand may not touch it?				___

FINE MOTOR TOTAL ___

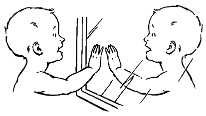
PROBLEM SOLVING

	YES	SOMETIMES	NOT YET	
1. When you move a toy slowly from side to side in front of your baby's face (about 10 inches away), does your baby follow the toy with his eyes, sometimes turning his head?				___
2. When you move a small toy up and down slowly in front of your baby's face (about 10 inches away), does your baby follow the toy with her eyes?				___
3. When you hold your baby in a sitting position, does he look at a toy (about the size of a cup or rattle) that you place on the table or floor in front of him?				___
4. When you put a toy in her hand, does your baby look at it?				___
5. When you put a toy in his hand, does your baby put the toy in his mouth?				___

PROBLEM SOLVING *(continued)*

		YES	SOMETIMES	NOT YET	
6.	When you dangle a toy above your baby while she is lying on her back, does your baby wave her arms toward the toy? 	○	○	○	___
			PROBLEM SOLVING TOTAL		___

PERSONAL-SOCIAL

		YES	SOMETIMES	NOT YET	
1.	Does your baby watch his hands? 	○	○	○	___
2.	When your baby has her hands together, does she play with her fingers?	○	○	○	___
3.	When your baby sees the breast or bottle, does he seem to know he is about to be fed?	○	○	○	___
4.	Does your baby help hold the bottle with both hands at once, or when nursing, does she hold the breast with her free hand?	○	○	○	___
5.	Before you smile or talk to your baby, does he smile when he sees you nearby?	○	○	○	___
6.	When in front of a large mirror, does your baby smile or coo at herself? 	○	○	○	___
			PERSONAL-SOCIAL TOTAL		___

OVERALL

Parents and providers may use the space below for additional comments.

1. Does your baby use both hands and both legs equally well? If no, explain: ○ YES ○ NO

2. When you help your baby stand, are his feet flat on the surface most of the time? If no, explain: ○ YES ○ NO

ASQ-3™

6 Month Questionnaire

5 months 0 days through 6 months 30 days

On the following pages are questions about activities babies may do. Your baby may have already done some of the activities described here, and there may be some your baby has not begun doing yet. For each item, please fill in the circle that indicates whether your baby is doing the activity regularly, sometimes, or not yet.

Important Points to Remember:

- ☑ Try each activity with your baby before marking a response.
- ☑ Make completing this questionnaire a game that is fun for you and your baby.
- ☑ Make sure your baby is rested and fed.
- ☑ Please return this questionnaire by ______________.

Notes:

____

____

____

____

COMMUNICATION

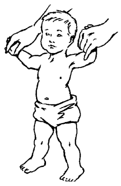
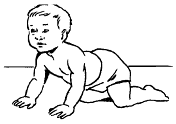
	YES	SOMETIMES	NOT YET	
1. Does your baby make high-pitched squeals?	○	○	○	___
2. When playing with sounds, does your baby make grunting, growling, or other deep-toned sounds?	○	○	○	___
3. If you call your baby when you are out of sight, does she look in the direction of your voice?	○	○	○	___
4. When a loud noise occurs, does your baby turn to see where the sound came from?	○	○	○	___
5. Does your baby make sounds like "da," "ga," "ka," and "ba"?	○	○	○	___
6. If you copy the sounds your baby makes, does your baby repeat the same sounds back to you?	○	○	○	___

COMMUNICATION TOTAL ___

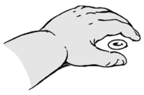
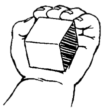
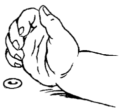
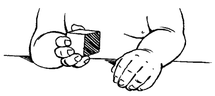
GROSS MOTOR

	YES	SOMETIMES	NOT YET	
1. While your baby is on his back, does your baby lift his legs high enough to see his feet?	○	○	○	___
2. When your baby is on her tummy, does she straighten both arms and push her whole chest off the bed or floor?	○	○	○	___
3. Does your baby roll from his back to his tummy, getting both arms out from under him?	○	○	○	___
4. When you put your baby on the floor, does she lean on her hands while sitting? *(If she already sits up straight without leaning on her hands, mark "yes" for this item.)*	○	○	○	___

GROSS MOTOR *(continued)*

	YES	SOMETIMES	NOT YET	
5. If you hold both hands just to balance your baby, does he support his own weight while standing? 	○	○	○	___
6. Does your baby get into a crawling position by getting up on her hands and knees? 	○	○	○	___
			GROSS MOTOR TOTAL	___

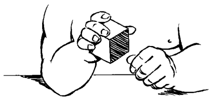
FINE MOTOR

	YES	SOMETIMES	NOT YET	
1. Does your baby grab a toy you offer and look at it, wave it about, or chew on it for about 1 minute?	○	○	○	___
2. Does your baby reach for or grasp a toy using both hands at once?	○	○	○	___
3. Does your baby reach for a crumb or Cheerio and touch it with his finger or hand? *(If he already picks up a small object the size of a pea, mark "yes" for this item.)* 	○	○	○	___
4. Does your baby pick up a small toy, holding it in the center of her hand with her fingers around it? 	○	○	○	___
5. Does your baby *try* to pick up a crumb or Cheerio by using his thumb and all of his fingers in a raking motion, even if he isn't able to pick it up? *(If he already picks up the crumb or Cheerio, mark "yes" for this item.)* 	○	○	○	___
6. Does your baby pick up a small toy with only one hand? 	○	○	○	___
			FINE MOTOR TOTAL	___

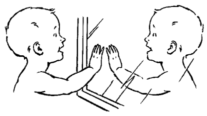
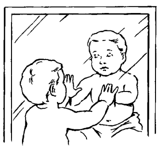
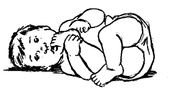
PROBLEM SOLVING

	YES	SOMETIMES	NOT YET	
1. When a toy is in front of your baby, does she reach for it with both hands?	○	○	○	___
2. When your baby is on his back, does he turn his head to look for a toy when he drops it? *(If he already picks it up, mark "yes" for this item.)*	○	○	○	___
3. When your baby is on her back, does she try to get a toy she has dropped if she can see it?	○	○	○	___
				___

PROBLEM SOLVING *(continued)*

		YES	SOMETIMES	NOT YET	
4. Does your baby pick up a toy and put it in his mouth?		○	○	○	___
5. Does your baby pass a toy back and forth from one hand to the other?		○	○	○	___
6. Does your baby play by banging a toy up and down on the floor or table?		○	○	○	___
			PROBLEM SOLVING TOTAL		___

PERSONAL-SOCIAL

		YES	SOMETIMES	NOT YET	
1. When in front of a large mirror, does your baby smile or coo at herself?		○	○	○	___
2. Does your baby act differently toward strangers than he does with you and other familiar people? *(Reactions to strangers may include staring, frowning, withdrawing, or crying.)*		○	○	○	___
3. While lying on her back, does your baby play by grabbing her foot?		○	○	○	___
4. When in front of a large mirror, does your baby reach out to pat the mirror?		○	○	○	___
5. While your baby is on his back, does he put his foot in his mouth?		○	○	○	___
6. Does your baby try to get a toy that is out of reach? *(She may roll, pivot on her tummy, or crawl to get it.)*		○	○	○	___
			PERSONAL-SOCIAL TOTAL		___

ASQ-3™

8 Month Questionnaire

7 months 0 days through 8 months 30 days

On the following pages are questions about activities babies may do. Your baby may have already done some of the activities described here, and there may be some your baby has not begun doing yet. For each item, please fill in the circle that indicates whether your baby is doing the activity regularly, sometimes, or not yet.

Important Points to Remember:

- ☑ Try each activity with your baby before marking a response.
- ☑ Make completing this questionnaire a game that is fun for you and your baby.
- ☑ Make sure your baby is rested and fed.
- ☑ Please return this questionnaire by ______________.

Notes:

____

____

____

____

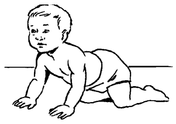
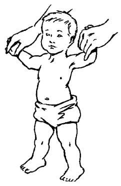
COMMUNICATION

	YES	SOMETIMES	NOT YET	
1. If you call to your baby when you are out of sight, does she look in the direction of your voice?	○	○	○	___
2. When a loud noise occurs, does your baby turn to see where the sound came from?	○	○	○	___
3. If you copy the sounds your baby makes, does your baby repeat the same sounds back to you?	○	○	○	___
4. Does your baby make sounds like "da," "ga," "ka," and "ba"?	○	○	○	___
5. Does your baby respond to the tone of your voice and stop his activity at least briefly when you say "no-no" to him?	○	○	○	___
6. Does your baby make two similar sounds like "ba-ba," "da-da," or "ga-ga"? *(The sounds do not need to mean anything.)*	○	○	○	___
			COMMUNICATION TOTAL	___

GROSS MOTOR

	YES	SOMETIMES	NOT YET	
1. When you put your baby on the floor, does she lean on her hands while sitting? *(If she already sits up straight without leaning on her hands, mark "yes" for this item.)* 	○	○	○	___
2. Does your baby roll from his back to his tummy, getting both arms out from under him?	○	○	○	___

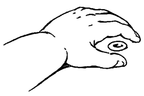
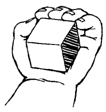
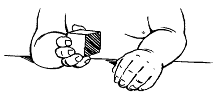
GROSS MOTOR *(continued)*

		YES	SOMETIMES	NOT YET	
3. Does your baby get into a crawling position by getting up on her hands and knees?		○	○	○	___
4. If you hold both hands just to balance your baby, does he support his own weight while standing?		○	○	○	___
5. When sitting on the floor, does your baby sit up straight for several minutes *without* using her hands for support?		○	○	○	___ *
6. When you stand your baby next to furniture or the crib rail, does he hold on without leaning his chest against the furniture for support?		○	○	○	___

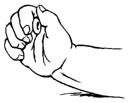
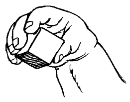
GROSS MOTOR TOTAL ___

**If Gross Motor Item 5 is marked "yes" or "sometimes," mark Gross Motor Item 1 "yes."*

FINE MOTOR

		YES	SOMETIMES	NOT YET	
1. Does your baby reach for a crumb or Cheerio and touch it with her finger or hand? *(If she already picks up a small object, mark "yes" for this item.)*		○	○	○	___
2. Does your baby pick up a small toy, holding it in the center of his hand with his fingers around it?		○	○	○	___
3. Does your baby *try* to pick up a crumb or Cheerio by using her thumb and all of her fingers in a raking motion, even if she isn't able to pick it up? *(If she already picks up a crumb or Cheerio, mark "yes" for this item.)*		○	○	○	___
4. Does your baby pick up a small toy with only one hand?		○	○	○	___

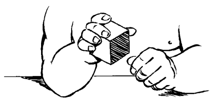
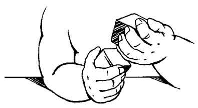
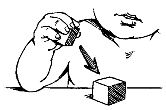
FINE MOTOR *(continued)*

	YES	SOMETIMES	NOT YET	
5. Does your baby *successfully* pick up a crumb or Cheerio by using his thumb and all of his fingers in a raking motion? *(If he already picks up a crumb or Cheerio, mark "yes" for this item.)* 	○	○	○	___
6. Does your baby pick up a small toy with the *tips* of her thumb and fingers? *(You should see a space between the toy and her palm.)* 	○	○	○	___ *

FINE MOTOR TOTAL ___

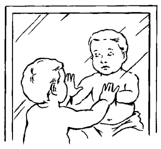
**If Fine Motor Item 6 is marked "yes" or "sometimes," mark Fine Motor Item 2 "yes."*

PROBLEM SOLVING

	YES	SOMETIMES	NOT YET	
1. Does your baby pick up a toy and put it in his mouth? 	○	○	○	___
2. When your baby is on her back, does she try to get a toy she has dropped if she can see it?	○	○	○	___
3. Does your baby play by banging a toy up and down on the floor or table? 	○	○	○	___
4. Does your baby pass a toy back and forth from one hand to the other? 	○	○	○	___
5. Does your baby pick up two small toys, one in each hand, and hold onto them for about 1 minute? 	○	○	○	___
6. When holding a toy in his hand, does your baby bang it against another toy on the table? 	○	○	○	___

PROBLEM SOLVING TOTAL ___

PERSONAL-SOCIAL

	YES	SOMETIMES	NOT YET	
1. When lying on her back, does your baby play by grabbing her foot? 	○	○	○	___
2. When in front of a large mirror, does your baby reach out to pat the mirror? 	○	○	○	___
3. Does your baby try to get a toy that is out of reach? *(He may roll, pivot on his tummy, or crawl to get it.)*	○	○	○	___
4. While your baby is on her back, does she put her foot in her mouth? 	○	○	○	___
5. Does your baby drink water, juice, or formula from a cup while you hold it?	○	○	○	___
6. Does your baby feed himself a cracker or a cookie?	○	○	○	___

PERSONAL-SOCIAL TOTAL ___

OVERALL

Parents and providers may use the space below for additional comments.

1. Does your baby use both hands and both legs equally well? If no, explain: ○ YES ○ NO

2. When you help your baby stand, are his feet flat on the surface most of the time? If no, explain: ○ YES ○ NO

10 Month Questionnaire

9 months 0 days through 10 months 30 days

On the following pages are questions about activities babies may do. Your baby may have already done some of the activities described here, and there may be some your baby has not begun doing yet. For each item, please fill in the circle that indicates whether your baby is doing the activity regularly, sometimes, or not yet.

Important Points to Remember:

- ☑ Try each activity with your baby before marking a response.
- ☑ Make completing this questionnaire a game that is fun for you and your baby.
- ☑ Make sure your baby is rested and fed.
- ☑ Please return this questionnaire by _______________.

Notes:

____

____

____

____

COMMUNICATION

	YES	SOMETIMES	NOT YET	
1. Does your baby make sounds like "da," "ga," "ka," and "ba"?	○	○	○	___
2. If you copy the sounds your baby makes, does your baby repeat the same sounds back to you?	○	○	○	___
3. Does your baby make two similar sounds like "ba-ba," "da-da," or "ga-ga"? *(The sounds do not need to mean anything.)*	○	○	○	___
4. If you ask your baby to, does he play at least one nursery game even if you don't show him the activity yourself (such as "bye-bye," "Peeka-boo," "clap your hands," "So Big")?	○	○	○	___
5. Does your baby follow one simple command, such as "Come here," "Give it to me," or "Put it back," *without* your using gestures?	○	○	○	___
6. Does your baby say three words, such as "Mama," "Dada," and "Baba"? *(A "word" is a sound or sounds your baby says consistently to mean someone or something.)*	○	○	○	___
		COMMUNICATION TOTAL		___

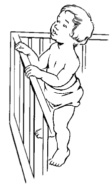
GROSS MOTOR

	YES	SOMETIMES	NOT YET	
1. If you hold both hands just to balance your baby, does she support her own weight while standing? 	○	○	○	___
2. When sitting on the floor, does your baby sit up straight for several minutes *without* using his hands for support? 	○	○	○	___

GROSS MOTOR *(continued)*

YES SOMETIMES NOT YET

3. When you stand your baby next to furniture or the crib rail, does she hold on without leaning her chest against the furniture for support?



4. While holding onto furniture, does your baby bend down and pick up a toy from the floor and then return to a standing position?

5. While holding onto furniture, does your baby lower himself with control (without falling or flopping down)?

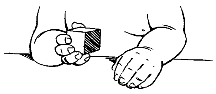
6. Does your baby walk beside furniture while holding on with only one hand?

GROSS MOTOR TOTAL

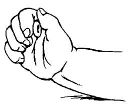
FINE MOTOR

YES SOMETIMES NOT YET

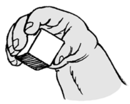
1. Does your baby pick up a small toy with only one hand?



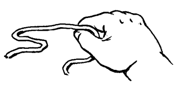
2. Does your baby *successfully* pick up a crumb or Cheerio by using her thumb and all of her fingers in a raking motion? *(If she already picks up a crumb or Cheerio, mark "yes" for this item.)*



3. Does your baby pick up a small toy with the *tips* of his thumb and fingers? *(You should see a space between the toy and his palm.)*



4. After one or two tries, does your baby pick up a piece of string with her first finger and thumb? *(The string may be attached to a toy.)*



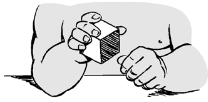
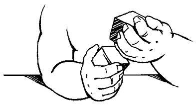
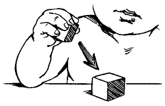
5. Does your baby pick up a crumb or Cheerio with the *tips* of his thumb and a finger? He may rest his arm or hand on the table while doing it. *

6. Does your baby put a small toy down, without dropping it, and then take her hand off the toy?

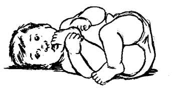
FINE MOTOR TOTAL

**If Fine Motor Item 5 is marked "yes" or "sometimes," mark Fine Motor Item 2 "yes."*

PROBLEM SOLVING

	YES	SOMETIMES	NOT YET	
1. Does your baby pass a toy back and forth from one hand to the other? 	○	○	○	___
2. Does your baby pick up two small toys, one in each hand, and hold onto them for about 1 minute? 	○	○	○	___
3. When holding a toy in his hand, does your baby bang it against another toy on the table? 	○	○	○	___
4. While holding a small toy in each hand, does your baby clap the toys together (like "Pat-a-cake")?	○	○	○	___
5. Does your baby poke at or try to get a crumb or Cheerio that is inside a clear bottle (such as a plastic soda-pop bottle or baby bottle)?	○	○	○	___
6. After watching you hide a small toy under a piece of paper or cloth, does your baby find it? *(Be sure the toy is completely hidden.)*	○	○	○	___
			PROBLEM SOLVING TOTAL	___

PERSONAL-SOCIAL

	YES	SOMETIMES	NOT YET	
1. While your baby is on her back, does she put her foot in her mouth? 	○	○	○	___
2. Does your baby drink water, juice, or formula from a cup while you hold it?	○	○	○	___
3. Does your baby feed himself a cracker or a cookie?	○	○	○	___
4. When you hold out your hand and ask for her toy, does your baby offer it to you even if she doesn't let go of it? *(If she already lets go of the toy into your hand, mark "yes" for this item.)*	○	○	○	___
5. When you dress your baby, does he push his arm through a sleeve once his arm is started in the hole of the sleeve?	○	○	○	___
6. When you hold out your hand and ask for her toy, does your baby let go of it into your hand?	○	○	○	___
			PERSONAL-SOCIAL TOTAL	___

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